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CONTENTS

PAGE

WILSON, H. H. The Cove Marine Bands in East Lothian and their Relation to the Ironstone Shale and Limestone of Redesdale, Northumberland 305
WRIGHT, J. Crinoids from Thornton Burn, East Lothian . . 320
PITCHER, W. S., and READ, H. H. An Appinitic Intrusion-Breccia at Kilkenny, Maas, Co. Donegal 328
WALKER, F. Mugearites and Oligoclase-Basalts 337
FORD, T. D. New Evidence on the Correlation of the Lower Carboniferous Reefs at Castleton, North Derbyshire 346
JOYSEY, K. A. Fossil Lineages and Environmental Change . . 357
JOHNSON, G. A. L. A glacial erratic boulder of Shap Granite in South Northumberland 361
STRACHAN, I. On the Development of *Diversograptus* Manck . . 365
BAILEY, E. B. So-called Amygdaloidal Gabbro, Skye 369
REYNOLDS, D. L. So-called Amygdaloidal Gabbro, Skye: Comments on a paper by E. B. Bailey 376

REVIEWS

pp. 380–2

CORRESPONDENCE

Pleistocene Sections at Barrington 382
Malvern Tectonics 384

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GEOLOGICAL MAGAZINE

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The Cove Marine Bands in East Lothian and their Relation to the Ironstone Shale and Limestone of Redesdale, Northumberland

By H. HUGH WILSON

(PLATES XI AND XII)

ABSTRACT

Study of the fauna from a newly discovered fossiliferous outcrop of the Cove Lower Marine Band in Thornton Burn, East Lothian, has led to the correlation of this horizon with the Redesdale Ironstone in Northumberland and has thereby demonstrated the first palaeontological link between the Upper Calciferous Sandstone in S.E. Scotland and the Lower Limestone Group in N.E. England. The collection of D_1 fauna made from the Thornton Burn outcrop includes goniatites, brachiopods, lamellibranchs, and crinoids. The discovery of *Beyrichoceratoides redesdalensis* (Hind) gives the first definite indication of the presence of B zone in the Scottish Carboniferous. Faunal lists and descriptions of some of the more interesting species are included in this paper as well as descriptions of the crinoids collected which are given in the succeeding paper by James Wright.

I. INTRODUCTION

THE existence of the two Cove Marine Bands in the Upper Calciferous Sandstone of the Dunbar–Cockburnspath district, East Lothian, has been known for some time. The bands can be seen in Cove Harbour where they are separated by 60 feet of sandstones and shales. On the coast two miles north-west of Cove Harbour, near Thorntonloch, is the Linkhead "Limestone" which bears little resemblance to either of the Marine Bands exposed in Cove Harbour; its relationship to one or the other of these has hitherto been a point of conjecture.

So far as was known there were no other horizons containing marine fossils below the Long Craig Lower Limestone which has been placed at the base of the Lower Limestone Group of Scotland.

Gunn (1898, p. 366) suggested that the Cove Upper "Limestone" was the equivalent of the Dun and Woodend Limestones in Northumberland and that the Linkhead "Limestone" corresponded to the Oxford Limestone in Northumberland. Clough (1910, pp. 45–7) discovered the Cove Lower "Limestone" and suggested that it represented the Dun Limestone and that the Cove Upper and Linkhead "Limestones" were equivalent and corresponded to the Woodend

Limestone in Northumberland. Both correlations were based on a certain lithological similarity between the sedimentary sequence above and below the Dun and Woodend Limestones in the Berwick-on-Tweed district and that above and below the Cove Marine Bands. In the Berwick-on-Tweed district the Woodend Limestone occurs some 600 feet below the Oxford Limestone but the succession between the Cove Upper Marine Band and the base of the Scottish Lower Limestone Group is disrupted by faulting so that it is not possible to estimate the intervening thickness.

The remarkable variations in thickness and lithology which occur from place to place in sediments of the Calciferous Sandstone Series makes correlation, if based only on lithological evidence, both difficult and unreliable. Even the marine bands, which one would expect to be of a more uniform nature, are themselves so varied that their interrelationships are often difficult to establish. Details given below (Section II) illustrate this point with regard to the Cove Marine Bands.

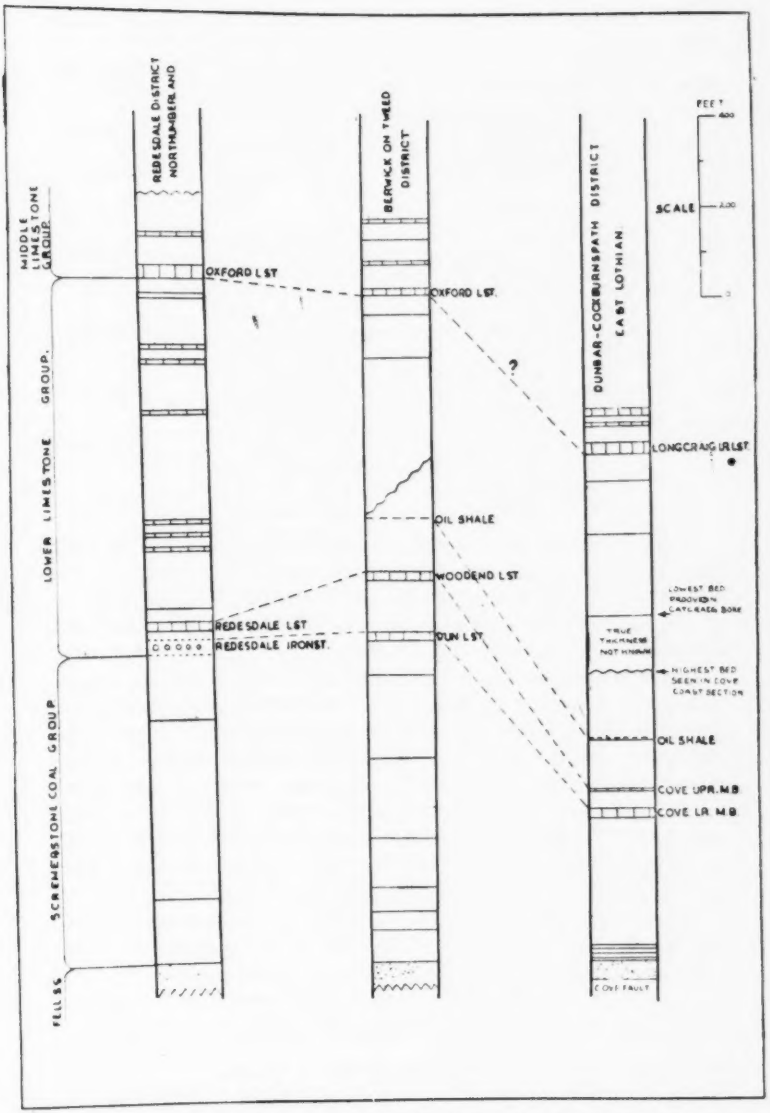
In the absence of adequate palaeontological evidence the correlations of the Cove Marine Bands with the Dun and Woodend Limestones could be regarded as only tentative.

During a recent survey of the Carboniferous rocks in the Dunbar–Cockburnspath district one of the author's objects was to obtain more information about the Cove Marine Bands both with regard to their extent within the district and their relationship to marine horizons in the north of England. Much time was spent looking for fossils in the two localities mentioned above, but with little success since fossils are both scarce and poorly preserved. However, the later discovery of four previously unrecognized fossiliferous outcrops of the Cove Lower Marine Band in Thornton Burn, 4½ miles south-east of Dunbar, proved of the greatest interest. One of these outcrops, an exposure of a 2 ft. fossiliferous ironstone-shale near Thornton Laundry Mill, furnished a remarkably varied fauna, much of which is in a good state of preservation. It is upon the fossils collected from this outcrop and the conclusions that can be drawn therefrom that this paper is mainly based.

II. The Correlation of Outcrops of the Cove Marine Bands [1] and Faunal Lists

Fossil collections made from the three previously known outcrops of the Cove Marine Bands and from the four newly discovered exposures in Thornton Burn have clarified the relationship of these outcrops.

[1] The author suggests that the Cove Marine Bands should not be referred to as limestones since at no locality is a true limestone exposed.



TEXT-FIG. 1.—Generalized stratigraphical columns showing the correlation of marine horizons suggested in this paper (mainly after H.M. Geol. Survey publications).

The localities now known and suggested correlations are as follows :—

	National Grid References.
Cove Upper Marine Band.	
A. In Cove Harbour at seaward end of south pier. 3 feet of calcareous shale and impure limestone . .	36/786718
B. On coast at Linkhead 6 miles S.E. of Dunbar. 8 feet of calcareous sandstone	36/760735
Cove Lower Marine Band.	
1. In Cove Harbour. 10 yards south of crook in south pier. 18 feet of calcareous sandstone . . .	36/786717
2. In Thornton Burn. 100 yards upstream from Thornton Laundry Mill. 2 feet of calcareous ironstone-shale below 10 feet of barren ironstone-shale. Seen in both banks near the bed of the burn . .	36/741741
3. In Thornton Burn. 80 yards downstream from Thornton village footbridge. 8 feet of marly shale with septarian nodules seen high up in right bank .	36/737735
4. In Thornton Burn. Left bank opposite Thornton village. 8 feet of calcareous sandy shale with courses of ironstone nodules	36/738734
5. In Thornton Burn. 50 yards upstream from Thornton sandstone quarry in right bank. 6 feet of calcareous sandstone	36/737732

A study of the fossil contents of the different outcrops has clarified their inter-relationship and it is on a palaeontological basis that the outcrops have been assigned to the Upper or Lower Marine Band.

The characteristic fossils in the Cove Upper Marine Band are *Spirifer duplicicosta* and *Gigantoproductus* sp. The former occurs abundantly near the top of both the Cove and Linkhead outcrops. *Lithostrotion junceum* is characteristic of the Linkhead outcrop of the Upper Marine Band but has not so far been found in the Cove Harbour outcrop. These three species are entirely absent from the Lower Marine Band, which is characterized by an abundance of *Productus redesdalensis* and *P. undatus*, neither of which has been found in the Upper Marine Band. Ammodiscid foraminifera, which are common in the Cove Harbour (No. 1) and Thornton Mill (No. 2) outcrops, have not been found in the Upper Marine Band.

On account of the scarcity of well preserved fossils in all outcrops except that near Thornton Mill (No. 2) a detailed comparison of the fossil assemblages of the two Marine Bands is not possible.

Faunal lists are given below with outcrop letters or numbers to indicate the localities from which the particular species were collected.

FAUNAL LISTS

Cove Upper Marine Band.	*Localities.*
Lithostrotion junceum Fleming	B
Chaetetes sp.	B
Fenestrellina sp.	B
Gigantoproductus sp.	A, B

	Localities.
Lingula squamiformis Phillips	B
Orbiculoidea nitida (Phillips)	A, B
Punctospirifer scabricosta North	A, B
Spirifer duplicicosta Phillips	A, B
Aviculopecten cf. *gentilis* (J. de C. Sowerby)	A
Parallelodon sp.	A
Hesperiella loudoni Grey Thomas	A
" *Orthoceras* " sp.	A, B
Archaeocidaris urii (Fleming)	B
Crinoid ossicles	A, B
Fish scales	A
Cove Lower Marine Band [1]	
Ammodiscids	1, 2
**Chaetetes* sp.	2
Fenestrellina polyporata (Phillips)	2
**Productus redesdalensis* Muir-Wood	1, 2
**Productus undatus* de France	2, 4
**Echinoconchus punctatus* (Martin)	4
Buxtonia cf. *scabricula* (Martin)	2, 3, 4
**Punctospirifer scabricosta* mut. *redesdalensis* North	1, 2, 4
Camarotoechia pleurodon (Phillips)	2
Composita sp. nov.	1, 4, 5
" *Terebratula* " *vesicularis* de Koninck	1
**Orbiculoidea nitida* (Phillips)	2
**Lingula mytiloides* J. Sowerby	2
**Edmondia pentonensis* Hind	2
**E. sulcata* Phillips	2
E. expansa Hind	2
**Sanguinolites tricostatus* (Portlock)	2
S. subcarinatus McCoy	2
**S. plicatus* (Portlock)	2
S. striato-lamellosus (de Koninck)	1
Pinna flabelliformis (Martin)	1, 2
**P. mutica* McCoy	1, 2
Limatulina scotica Hind	2
Aviculopecten clathratus McCoy	2
**A. semicostatus* (Portlock)	1, 2
A. dissimilis (Fleming)	2, 4
Pseudamusium anisotum (Phillips)	4
Solemya cf. *primaeva* Phillips	2, 4
**Schizodus axiniformis* Phillips	1
*" *Nucula* " *laevirostris* (Portlock)	1, 2
**Nuculopsis gibbosa* (Fleming)	2
**Nuculana attenuata* (Fleming)	2
**Loxonema* cf. *murchisoniana* de Koninck	2, 4
Euphemites cf. *urei* (Fleming)	2
**Conularia quadrisulcata* Sowerby	2
Coleolus sp.	2
" *Orthoceras* " sp.	2
**Stroboceras sulcatum* (J. de C. Sowerby)	2
**Beyrichoceratoides redesdalensis* (Hind)	2, 4
**Archaeocidaris urii* (Fleming)	2

[1] With the exception of the crinoids, which are in Mr. James Wright's collection, the fossils collected from the Cove Lower Marine Band are in the custody of the Hunterian Museum, Glasgow. All specimens figured in this paper have been given provisional Hunterian Museum numbers.

* Species known to occur in the Redesdale Ironstone.

	Localities.
†**Talanterocrinus redesdalensis* sp. nov.	2
†*Anemetocrinus wilsoni* sp. nov.	2
†*Blothrocrinus thorntonensis* sp. nov.	2
Ureocrinus doliolus Wright	2
U. bockschii Geinitz	2
Phanocrinus ardrossensis Wright	2
Fish scales and spines	2
Bairdiids	2

* Species known to occur in the Redesdale Ironstone.
† Described in the Appendix to this paper by James Wright.

III. Description of Species from the Cove Lower Marine Band

Productus redesdalensis Muir-Wood (Plate XII, figs. 4, 5, 6, 7).

This species is the most abundant brachiopod in the Cove Lower Marine Band. About forty specimens were collected and careful examination of these has revealed features which have hitherto been undescribed in this species.

A few specimens about which the author was doubtful were sent to Dr. H. M. Muir-Wood, who kindly confirmed the author's tentative identification.

The following features are here described in detail : (*a*) the cardinal process and " anal tube " (Plate XII, figs. 6, 7), (*b*) the adductor scars and brachial ridges in the brachial valve (Plate XII, fig. 4), (*c*) the adductor and divaricator scars in the pedicle valve (Plate XII, fig. 5).

(*a*) The cardinal process is small and bifid ventrally but trifid dorsally. The dorsal lobes bear deep incisions. On the median lobe the incisions are in the form of shallow chevrons with anteriorly directed apices. The two lateral lobes bear incisions set longitudinally and more or less at right angles to those on the median lobe.

In the central line of the pedicle valve, just anterior to the cardinal process and close to the umbo, is the cast of a knob-like process. This process has been observed before in species of the *Productus* s.s. group, and it has been suggested that it may be related to an anal tube.

(*b*) The adductor impressions in the brachial valve show that the main point of attachment is in the form of an elongated raised platform set close to the median septum. About this main platform are six subsidiary scars. Three of these scars are sub-circular in shape and are set one behind the other in a line parallel with the main platform. The other three scars are low ridges set posteriorly to the main platform.

The brachial ridges appear to be normal except that instead of diverging at right angles to the median septum they have a slight anterior deflection. This is well seen in two specimens from Thornton Burn.

(*c*) The divaricator scars in the pedicle valve are large and subtriangular and bear longitudinal striations. The adductor scars are

elongated and lie on either side of the median line, where they are enclosed by the divaricator scars except for their anterior extremities which project slightly beyond those scars.

Among the specimens collected from Thornton Burn were some that have a much longer trail than is typical in *P. redesdalensis*, which more closely resemble *P. productus* (Martin). Others bear a median fold in the trail and seem to come closer to *P. concinnus* J. Sowerby.

It will be gathered that the *P. redesdalensis* community in the Cove Lower Marine Band is remarkable for its morphological diversity. If this be a characteristic of communities of species of the *Productus s.s.* group the difficulties in making specific identifications become readily understandable.

Buxtonia cf. **scabricula** (Martin) (Plate XI, fig. 9 ; Plate XII, figs. 1, 2).

One good specimen (L 3514) showing the interior of the brachial valve and three fragmentary specimens of this species were collected from the Cove Lower Marine Band. In external appearance the specimens seem to be normal except that they are rather smaller and the pedicle valve is less arched than is usual. However, the cardinal process and median septum are distinctive and worthy of description (Plate XII, figs. 1, 2).

The median septum is broad and flattened posteriorly where it is divided by a very shallow groove into two rounded shoulders. 2·5 mm. from the junction of the median septum with the marginal ridges the two shoulders coalesce and the septum continues as a single rod, which thins and becomes lath-like anteriorly. In this specimen the median septum is broken off anteriorly and can clearly be seen to be made up of two elements that are cemented together.

The cardinal process is strong and bilobed ventrally but the lobes unite dorsally. The process is directed postero-dorsally, making an angle of about 150° with the median septum. On the summit of the process where the two lobes unite on the ventral side are two incipient prominences which are in line with the main lobes.

The specimen differs from other described specimens of *Buxtonia* in the shallowness of the groove in the median septum, the greater width of the septum posteriorly, and the presence of two incipient prominences on the ventral side of the cardinal process.

Dimensions.	*Specimen.* (L. 3514).
Maximum width	45 mm.
Maximum thickness	45 mm.
Maximum height (brachial valve)	9 mm.
Length of hinge line	44 mm.
Length of median septum	? 18·5 mm.
Length of adductor impression	7·5 mm.
Width of adductor impression	4 mm.

Composita sp. nov. (Plate XII, fig. 3).

Four rather imperfect specimens were collected from the Cove Lower Marine Band and were at first assigned to *Composita ambigua* (J. Sowerby). However, one specimen (L. 3515), collected from No. 4 outcrop of the Cove Lower Marine Band, shows a cast of the interior of the pedicle valve and a comparison made with Davidson's (1861) figure of the interior of the pedicle valve of *Athyris ambigua* J. Sowerby (pl. xvii, fig. 13) showed that the Cove species differs in the following respects :—

(*a*) The dental plates are much wider apart and diverge anteriorly.

(*b*) The muscle scars are clearly separated from the hollow underlying the umbo.

(*c*) The divaricator scars are much more inflated posteriorly.

(*d*) There is a thin spear-shaped groove in the median line that extends from the anterior extremity of the adductor scars to near the anterior extremity of the divaricators.

The external appearance of the shell closely resembles that of *Composita ambigua* except that the median sulcus in the pedicle valve is somewhat deeper.

All the specimens collected are small, the maximum width of the largest specimen being 14 mm.

Beyrichoceratoides redesdalensis (Hind) (Plate XI, figs. 1–8, Text-fig. 2).

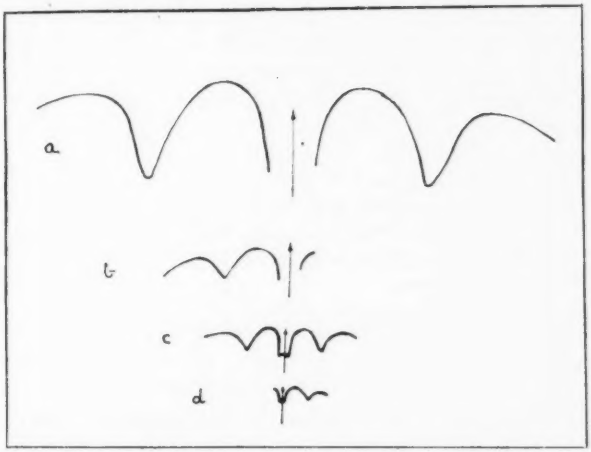
The goniatite material collected from the Cove Lower Marine Band (No. 2 outcrop) includes nineteen crushed fragments and six specimens in the round. There is little doubt that all these specimens belong to the species *B. redesdalensis*.

The best specimen (S. 11230) has a maximum diameter of 60 mm. and is almost complete (Plate XI, figs. 1–4). The shell is moderately inflated with a broadly rounded venter. The body cavity occupies a complete whorl so that the last suture is concealed by the aperture. The falcate ornament is indistinct at the umbilical margin but becomes strong on the flanks. At the latero-ventral shoulder the ornament again becomes indistinct, but the ribs are seen to swing sharply backwards and trace out a deep hyponomic sinus on the venter, which is practically smooth.

The last suture line was exposed by breaking away part of the last whorl, but unfortunately it is somewhat imperfectly preserved due to mineralization in the phragmacone. The ventral lobe (Text-fig. 2*a*) is wide with anteriorly diverging sides but the median saddle is not well seen. The ventral lobe is not so wide as that figured by Delépine (1940, p. 66), but his drawing does not appear to be very accurate, since the anterior ventral lobe is shown to be narrower than the one posterior

to it. The first lateral lobe is moderately deep and narrow and is similar to that figured by Delépine (1940, pl. iii, fig. 18).

The two small specimens, S. 11235 and S. 11234 (Plate XI, figs. 7, 8), are regarded as belonging to *Beyrichoceratoides redesdalensis* and have been included in the table of dimensions. They differ from the larger specimens in their more globose shape, presence of constrictions, and absence of strong ornament. However, in a letter to the author, Mr. Bisat indicated that variability in shape of shell is typical of specimens from Redesdale, which may vary from globose to compressed at various growth stages. It can be seen that the ventral lobe



TEXT-FIG. 2.—Suture lines of specimens of *Beyrichoceratoides redesdalensis* (Hind) from No. 2 outcrop of the Cove Lower Marine Band.

(a) Suture at Diameter 35 mm. × 2 (S. 11230)
(b) ,, ,, ,, 18 mm. × 2 (S. 11232)
(c) ,, ,, ,, 10·5 mm. × 2 (S. 11234)
(d) ,, ,, ,, 8 mm. × 2 (S. 11235)

of the suture is more like that of species belonging to the *Beyrichoceratoides truncatus* group, but the sides are not quite parallel (Text-fig. 2 *c*, *d*).

Bisat (1924, pp. 88–91) includes the Redesdale species in the group *Beyrichoceratoides*, but suggests that they are an early form and differ from other species of the group by their stronger ornament and wider umbilicus in adults and by the persistence of constrictions to a greater diameter than 12 mm. (See L. 3513 in table of dimensions.)

Delépine (1940, pp. 65–7) distinguishes between *Beyrichoceratoides redesdalensis* and *B. truncatus* (Phillips) by the shape of the ventral lobe of the suture, which has anteriorly diverging sides in the former

BEYRICHOCERATOIDES REDESDALENSIS (Hind)

Specimen.	*Max. diameter.*	*Whorl height above previous whorl.*	*Max. thickness.*	*Diameter of umbilicus.*	*D/h ratio.*	*Constrictions.*	*Ornament on flanks.*
S. 11230 .	60 mm.	18 mm.	27·5 mm.	8 mm.	3·3	0	Strong
S. 11231 .	35 mm.	?11 mm.	Crushed	3·5 mm.	3·1	0	Distinct
S. 11232 .	30 mm.	?10 mm.	Crushed	2·75 mm.	3	0	Indinstinct
S. 11233 .	21 mm.	7 mm.	10 mm.	?2 mm.	3	1 at D = 16 mm.	Indistinct
S. 11234 .	12 mm.	4 mm.	7·5 mm.	1·75 mm.	3	At least 1 at D = 10 mm.	Fine and Indistinct
S. 11235 .	8 mm.	4 mm.	6 mm.	1·5 mm.	2	3 seen probably, 4 at D = 8 mm.	Fine and Indistinct

Dimensions of specimens of *B. redesdalensis* collected from No. 2 outcrop of the Cove Lower Marine Band.

but parallel sides in the latter, and the D/h ratio which is greater in large specimens of the former than in the latter.

Since both Bisat's (1924) and Delépine's (1940) diagnostic features are displayed by specimens from the Cove Lower Marine Band it seems that a combination of the two diagnoses can now safely be used for the specific separation of *Beyrichoceratoides redesdalensis* and *B. truncatus*.

According to Delépine (1940, p. 65) the spiral groove which is such a strong feature in Hind's (1918) figure of the type specimen, and which is again mentioned by Bisat (1924, p. 89), is, in fact, due to crushing. The specimens from the Cove Lower Marine Band bear out the point that this feature is due to crushing, since the only specimen, S. 11231 (Pl. XI, fig. 6), that shows this groove has been slightly compressed. However, the fact that this is a recurrent feature in crushed specimens may be an indication of a weakness in the shell of this particular species.

Beyrichoceratoides redesdalensis has not previously been recorded from the Scottish Carboniferous, and since it is probably the marker for the lowest goniatite zone in Scotland its recognition is important.

Dr. E. D. Currie has kindly supplied the author with tracings of the suture lines of the specimens collected from the Cove Lower Marine Band (Text-fig. 2). Some of these sutures are incomplete, due to their poor preservation.

IV. A Comparison of the Fossil Assemblage in the Cove Lower Marine Band with that of the Redesdale Ironstone and the Correlations thereby Inferred

As already mentioned, the Thornton Mill (No. 2) outcrop of the Cove Lower Marine Band has yielded more abundant and better preserved fossils than the other outcrops. The following comparison is therefore based, in the main, on the collection made at that outcrop.

In the faunal list on pages 309–10 those species which are also known to occur in the Redesdale Ironstone have been marked with an asterisk so that a glance suffices to indicate the remarkable similarity between the two assemblages. It is also noteworthy that the relative abundance of certain species in both localities is strikingly similar.

Stanley Smith (1910, p. 603), in his faunal diagnosis of the Redesdale Ironstone, indicates that *Productus undatus* and *Lingula scotica* are characteristic species and that *Productus concinnus* and *Orbiculoidea nitida* are very abundant. He further states that the lamellibranchs are represented by a large number of species and that corals, with the exception of *Chaetetes* (olim *Alveolites*) are very rare.

Apart from *Lingula scotica*, which has not been found in any of the outcrops, the same faunal diagnosis can be applied to the Cove Lower Marine Band. It is assumed that the *P. concinnus* mentioned by Smith

is, in fact, *P. redesdalensis* which, according to Muir-Wood (1928), is characteristic of the Redesdale Ironstone.

The most useful index fossils collected were *Beyrichoceratoides redesdalensis* (which occurs associated with the nautiloid *Stroboceras sulcatum* as at Redesdale) and *Punctospirifer scabricosta* mut. *redesdalensis*. The discovery of three cups of *Talanterocrinus redesdalensis* which had previously been found only in the Redesdale Ironstone is significant.[1] The specimens of *Buxtonia* cf. *scabricula* collected from the Cove Lower Marine Band may well be the same as the *Productus* aff. *scabriculus* mentioned by Stanley Smith as one of the characteristic species in the Redesdale Ironstone.

This accumulation of palaeontological data leaves very little room for doubt that the Cove Lower Marine Band is the Scottish equivalent of the Redesdale Ironstone.

If the Cove Lower Marine Band is the same horizon as the Redesdale Ironstone then it can be inferred that the Cove Upper Marine Band is the Scottish equivalent of the Redesdale Limestone and the relative abundance of *Gigantoproductus* sp. and *Lithostrotion junceum* in both localities strengthens this assumption.

It remains but to trace these two marine horizons into the Northumberland and Berwick-on-Tweed districts. In the author's opinion the links are almost certainly to be found in the Dun and Woodend Limestones. As already mentioned there is a marked stratigraphical resemblance between the succession of strata about the Cove Marine Bands and that associated with the Dun and Woodend Limestones in the Berwick-on-Tweed district. Furthermore, the Dun and Woodend Limestones were considered to be the Northern extensions of the Redesdale horizons until Hedley (1931, p. 235) noted that H.M. Geological Survey had shown that the Redesdale horizon was much below that of the Dun Limestone. The author has not had an opportunity to study the Carboniferous rocks in the Berwick-on-Tweed district but in the light of evidence given in this paper he is inclined to believe that the Dun Limestone is, in fact, the same horizon as the Cove Lower Marine Band.

The Redesdale Ironstone, Dun Limestone, and Cove Lower Marine Band all mark the top of a group of carbonaceous rocks which in Northumberland are assigned to the Scremerston Coal Group. Furthermore, there is no thickening of this group in the Berwick-on-Tweed district, so that it does not seem possible that the Redesdale Marine horizons could have been replaced by part of the Scremerston Coal Group. Of the marine horizons occurring in the Lower Limestone Group in the Redesdale district, the Redesdale Limestone is by far the thickest and would therefore be expected to have a greater lateral

[1] See appendix by James Wright.

extent than the thin limestones that occur above it. In the author's opinion the non-occurrence of the additional marine horizons seen at Redesdale, in the Berwick-on-Tweed and Dunbar–Cockburnspath districts, is the result of differential rates of submergence at the time of deposition. This submergence was governed by the Silurian–Ordovician axis of the Southern Uplands about which was a relatively stable area bounded to the north and south by areas which were sinking at a greater rate. Thus in East Fife to the north of this axis there is a great thickening of sediments of Upper Calciferous Sandstone age accompanied by a number of marine horizons some of which may well be related to those seen between the Redesdale and Oxford Limestones in Northumberland.

V. Conclusions

The fossil collection made from the Cove Lower Marine Band is interesting for two main reasons. In the first place it is one of the most representative assemblages of D_1 fauna so far found in the Scottish Carboniferous. Secondly, if the Redesdale Ironstone lies in B zone, as the evidence suggests, then the goniatite correlation with the Cove Lower Marine Band is the first proof of the presence of that zone in the Scottish Carboniferous.

The correlation also gives strength to the inference that one of the Long Craig Limestones (which so far as is known are the next marine horizons above the Cove Upper Marine Band) is the equivalent of the Oxford Limestone in Northumberland and that the Skateraw Middle Limestone is the equivalent of the Acre Limestone in Northumberland.

Unfortunately, not enough is at present known about the Upper Calciferous Sandstone marine bands in the Edinburgh and Fife districts to be sure of their relation to the Cove Marine Bands. It seems possible, however, that the Encrinite bed in East Fife may represent one of these horizons.

The author hopes that this paper will be of assistance to those working in Scottish Carboniferous stratigraphy and, in particular, that it will encourage a further inquiry into the correlation of Upper Calciferous Sandstone marine bands.

VI. Acknowledgments

The author is indebted to the Shell Petroleum Company for the award of a post-graduate scholarship, tenable at the Grant Institute of Geology, University of Edinburgh, which has enabled him to carry out the investigation upon part of which this paper is based. He wishes to thank Professor A. Holmes for placing the facilities of the department at his disposal and Dr. A. M. Cockburn and Dr. G. Y. Craig for much helpful discussion during the course of the work.

The author would also like to express his sincere thanks to Mr. James Wright for his description of the crinoids and for the interest that he has taken in this paper; to Dr. E. D. Currie, of the Hunterian Museum, for her advice and assistance in the identification of the goniatites; to Mr. W. S. Bisat for his comments on the goniatites and the author's correlations; and finally to Professor T. N. George, of Glasgow University, and Dr. H. M. Muir-Wood, of the British Museum, for their remarks on some of the brachiopods collected.

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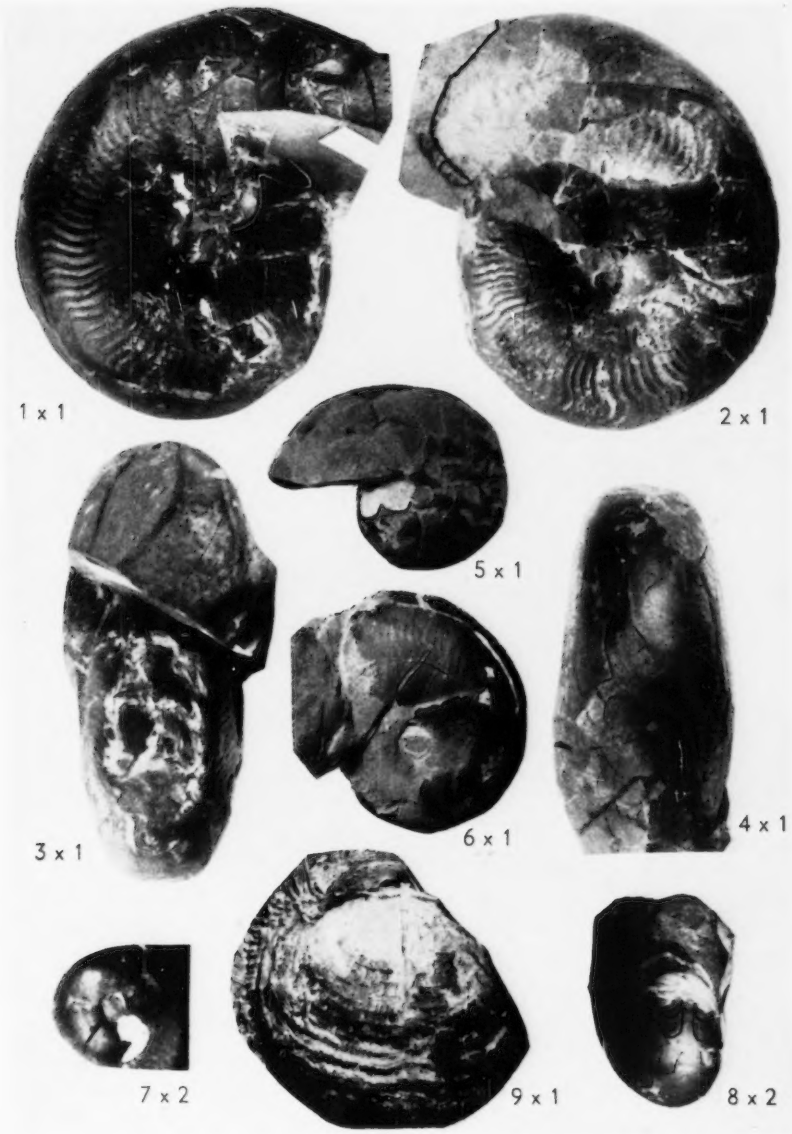
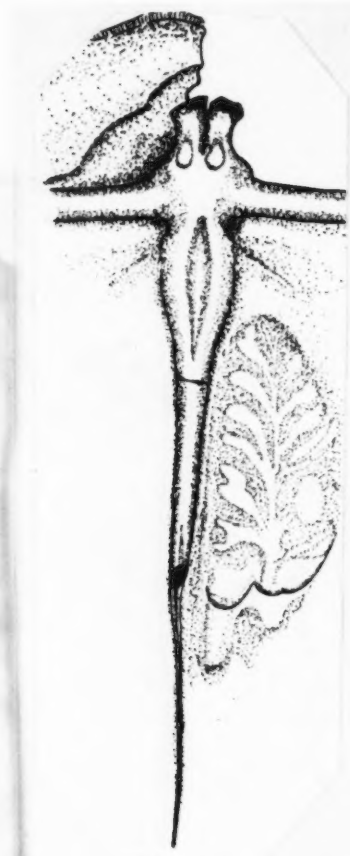


BEYRICHOCERATOIDES REDESDALENSIS AND BUXTONIA cf. SCABRICULA FROM THE COVE LOWER MARINE BAND.



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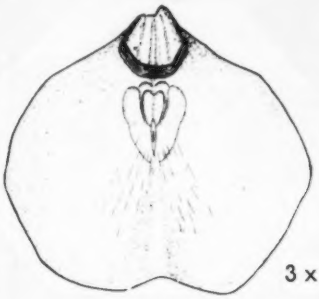

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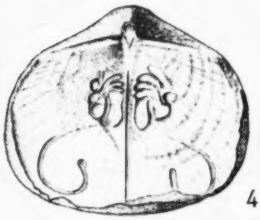

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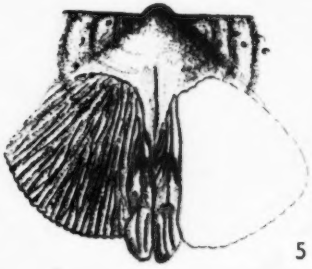

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BRACHIOPODS FROM THE COVE LOWER MARINE BAND.

EXPLANATION OF PLATE XI

Specimen numbers refer to the Hunterian Museum Collections.

FIG. 1. *Beyrichoceratoides redesdalensis* (Hind). View of large specimen showing part of the last suture, strong falcate ornament on the flanks and wide umbilicus. S. 11230.

2. —— Same specimen viewed from the other side showing the shape of the aperture and deep hyponomic sinus. S. 11230.

3. —— Same specimen viewed end on showing the general shape, outline of the venter, and whorl height above previous whorl. S. 11230.

4. —— Same specimen showing the smooth venter and hyponomic sinus. S. 11230.

5. —— A slightly crushed specimen with diameter 30 mm. showing part of the last suture (poorly preserved). S. 11232.

6. —— A slightly crushed specimen with diameter 35 mm. showing a spiral groove on the latero-ventral shoulder. S. 11231.

7. —— A specimen with diameter 8 mm. showing three constrictions and part of the last suture. S. 11235.

8. —— A specimen with diameter 12 mm. showing part of the last two sutures and one constriction. S. 11234.

9. *Buxtonia* cf. *scabricula* (Martin). Showing the interior of the brachial valve and part of the pedicle valve. L. 3514.

All from the Cove Lower Marine Band.

EXPLANATION OF PLATE XII

Specimen numbers refer to Hunterian Museum Collections.

Fig. 1. *Buxtonia* cf. *scabricula* (Martin). Ventral view of cardinal process, median septum and adductor scar. L. 3514.

2. *Buxtonia* cf. *scabricula* (Martin). Cardinal process viewed from side showing its postero-dorsal deflection. L. 3514.

3. *Composita* sp. nov. View of cast of pedicle valve showing position of muscle scars and dental plates. L. 3515.

4. *Productus redesdalensis* Muir-Wood. A specimen in which the internal layers of the brachial valve adhere to the pedicle valve, showing muscle scars and brachial ridges. L. 3510.

5. *Productus redesdalensis* Muir-Wood. A cast of the pedicle valve showing adductor and divaricator muscle scars. L. 3511.

6. *Productus redesdalensis* Muir-Wood. A cast of the dorsal side of the cardinal process showing the disposition of incisions in the three lobes. L. 3512.

7. *Productus redesdalensis* Muir-Wood. A section across the cardinal process showing it to be bi-lobed ventrally and tri-lobed dorsally. The incisions do not show on the median lobe because they lie in the plane of section. L. 3513.

All from the Cove Lower Marine Band.

Crinoids from Thornton Burn, East Lothian

By James Wright

(PLATE XIII)

THE crinoids collected by Mr. Hugh Wilson from the shales and ironstones of the Calciferous Sandstone Series in the Thornton Burn section in East Lothian are of special interest and are described herein. The list of species is as follows :—

Talanterocrinus redesdalensis sp. nov.
Blothrocrinus thorntonensis sp. nov.
Anemetocrinus wilsoni sp. nov.
Phanocrinus ardrossensis (Wright).
Ureocrinus bockschii (Geinitz).
Ureocrinus doliolus (Wright).

Apart from the three new species, this fauna is remarkable in that it comprises an assemblage of species not hitherto found together on any other horizon in the Scottish Lower Carboniferous rocks.

The writer wishes to express his thanks to Mr. Wilson for so generously presenting him with the specimens. These have now been given appropriate numbers as quoted below.

Sub Class **FLEXIBILIA** Zittel

Family Synerocrinidae Jaekel 1918

Genus **Talanterocrinus** Moore & Plummer, 1940

Talanterocrinus redesdalensis sp. nov.

Plate XIII, figs. 1, 2, 3, 7 ; Text-figs. 1, 2

Description.—Crown elongate ; base rather broad and rounded ; IBB entirely within ring of BB ; BB well seen beyond column ; PB rather long, extending nearly to upper limits of LPR and RPR, followed by a tube not connected to adjacent rays ; PBrBr two ; SBrBr usually three ; arms heterotomous, slightly incurved distally ; outer rami of each ray long, rounded, and giving off strong ramules on inner side ; inner rami narrower and much shorter, also with ramules on inner side of dichotom but considerably less prominent than in outer rami ; IBrBr comparatively few ; column expanding proximally.

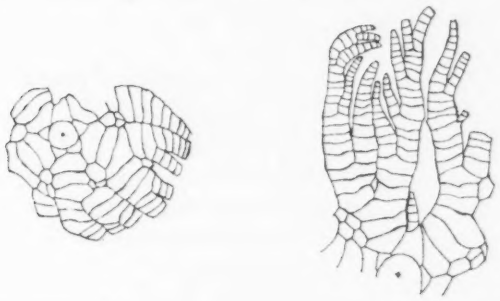
Holotype.—Hancock Museum, Newcastle-on-Tyne (Plate XIII, fig. 2).

Localities.—Redesdale, Northumberland ; Thornton Burn, East Lothian.

Horizon.—Visean (D_1), Calciferous Sandstone Series of Scotland.

Remarks.—The holotype of the present species is somewhat imperfect on the posterior side and stands out in relief on a hard block of ironstone with the distal part of the arms embedded in the matrix. The

specimen comes from Redesdale, Northumberland, and is now in the Hancock Museum, Newcastle-on-Tyne, along with three detached bases which probably belong to the same species. Some years ago, in preparing a description of these specimens for the *Monograph on British Carboniferous Crinoidea* (section Flexibilia, not yet published), the writer, with some hesitation, referred them to *Synerocrinus*, since, although the base agreed quite well with *Talanterocrinus*, the arms, as preserved in the holotype, seemed to have more in common with *Synerocrinus*. The discovery, however, by Mr. Wilson of three more or less complete crowns in the Thornton Burn section (Plate XIII, figs. 1, 3, 7) suggests beyond reasonable doubt that we are here



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TEXT-FIGS. 1, 2.—*Talanterocrinus redesdalensis* sp. nov.; Text-fig. 1, basal view of holotype from Redesdale; Text-fig. 2, posterior view of flattened crown from Thornton Burn, East Lothian, showing anal tube and left posterior ray almost complete. × 1.

dealing with the same species and that the arm characters, so well shown in at least one of the specimens (Plate XIII, fig. 1) indicate a genus like *Talanterocrinus* rather than *Synerocrinus*. (For discussion on *Synerocrinus* and *Talanterocrinus* see Wright, 1946, pp. 33–7.) It is true that in *Talanterocrinus jaekeli* Moore & Plummer, the type species, each ray consists of four much rounded and more or less equal arm trunks with the ramules given off as subordinate elements on the inside of each dichotom. In the present species the structure is somewhat different in that the outer rami are less rounded and the ramules relatively wide and heavy; the inner rami are conspicuously shorter and narrower, not of equal proportions with the outer rami as in *T. jaekeli* (Text-fig. 2). The best preserved crown, JW2528 (Plate XIII, fig. 1), is crushed, but allowing for this the incurving of the distal region of the arms appears to be less pronounced than in *T. jaekeli*. While the arm structure in the holotype is only preserved up to the fourth or fifth tertibrachs, the narrower character of the inner rami

is well seen (Text-fig. 1), and it is thus reasonable to suppose that the distal region is the same as that of the Thornton Burn specimens. Interbrachials are comparatively few in all the specimens, varying from three to four in the lower part of the inter-rays. There is usually a large hexagonal plate between the secundibrachs. The anal region is fairly uniform in all specimens, the large posterior basal (PB) extending nearly to the limits of LPR and RPR. The anal tube is missing in the holotype but is well seen in JW2528. The present species appears to be distinctive of the Thornton Burn and Redesdale beds since it is not known to occur elsewhere. Typical specimens, however, of *T. jaekeli* have been found in the shales above the Ardross limestone in Fife and a related species, *T. strimplei* Wright, in the Seafield Tower Limestone at Invertiel, Fife.

Sub Class **INADUNATA** Wachsmuth & Springer

Order CLADOIDEA Moore & Plummer, 1943

Sub Order DENDROCRINOIDEA Bather, 1899

Family BLOTHROCRINIDAE Moore & Laudon, 1943

Genus **Blothrocrinus** Kirk, 1940

Blothrocrinus thorntonensis sp. nov.

Plate XIII, fig. 9

Description.—Cup elongate conical ; IBB high, forming large part of cup walls ; BB large ; RR about same height as BB, crescentic ; sutures between RR moderately deep, others more or less flush ; anal area normal, RA, X, and RX of nearly equal size ; arms long, rather heavy, widely spaced but imperfectly known, dividing at least twice above primaxils ; PBrBr two and in one ray (right post.) three ; BrBr above primaxils markedly cuneate ; SBrBr eleven and sixteen ; ornament on cup plates coarsely granular ; column round, proximal columnals of nearly equal thickness.

Holotype.—JW 2532 (Plate XIII, fig. 9).

Locality.—Thornton Burn, East Lothian.

Horizon.—Visean (D_1), Calciferous Sandstone Series of Scotland.

Remarks.—The holotype is the only known specimen but is somewhat imperfect. The cup, however, is perfectly preserved and has three of the proximal columnals attached. The anal region is well seen but there is no trace of the ventral sac. Two only of the rays are moderately well preserved, the left posterior (left of photograph, Plate XIII, fig. 9), and the right posterior (middle of photograph). The right anterior ray is only partly seen (right of photograph) and no primibrachs are preserved. On the other side of specimen, the remaining rays are only represented by scattered plates. In referring this specimen

to *Blothrocrinus*, consideration has been given to the multiple branching of the arms and the fact that the left posterior ray has two primibrachs. These characters are in conformity with the definition of *Blothrocrinus* (Kirk, 1940, p. 321), and as seen in the type species *B. jesupi* (Whitfield, 1881, pls. i, ii) from the Burlington Limestone of the U.S.A. A difficulty in the determination arises, however, from the fact that in the right posterior ray there are three primibrachs instead of the usual two for the genus and since three of the rays are not preserved one wonders if this three primibrach character is of special significance in this species or is just a sporadic development in this particular specimen. In this connection, it may be mentioned that in another British inadunate species *Phacelocrinus rostratus* (T. & T. Austin), normally having two primibrachs, a specimen is known in which at least three of the rays exhibit three primibrachs (Wright, 1951, pl. viii, fig. 10). For the present therefore, the Thornton Burn species is retained in *Blothrocrinus*. It is of special interest since it is the first Inadunate crinoid with elongate cup and branching arms, in which the primibrachs number more than one, to be recorded from Scottish Lower Carboniferous rocks. It differs from previously described English and Irish Tournaisian forms like *Blothrocrinus longidactylus* (T. & T. Austin), *B. rugosus* (Grenfell), etc., in its larger size and much more widely spaced arms (Wright, 1951, pl. viii, figs. 5, 6 ; pl. x, figs. 1, 3, 5). The plates of cup and arms are now for the most part smooth, but distinct traces of the original coarse granular ornament are still visible along the sutural areas of the cup plates.

Family SCYTALOCRINIDAE Moore & Laudon, 1943

Genus **Anemetocrinus** Wright, 1938

Anemetocrinus wilsoni sp. nov.

Plate XIII, fig. 10 ; Text-figs. 3, 4

Description.—Cup somewhat low, conical ; IBB well seen from side, rounded ; BB and RR about same height ; RR crescentic ; anal area normal ; arms five, strongly biserial proximally, becoming cuneiform distally ; pinnules long, composed of eight or more strong elongate and tapering ossicles ; column slightly pentagonal proximally ; plates smooth.

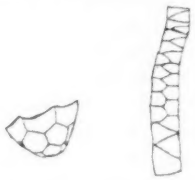
Holotype.—JW 2531 (Plate XIII, fig. 10).

Locality.—Thornton Burn, East Lothian.

Horizon.—Visean (D_1), Calciferous Sandstone Series of Scotland.

Remarks.—This species is represented by three detached cups and a slightly disturbed crown which is here chosen as holotype. The species is named in honour of Mr. Hugh Wilson, the discoverer of all these interesting crinoids at Thornton Burn. The present species differs from

others assigned to *Anemetocrinus* chiefly in the character of the arms. It has some resemblance to *A. covensis* (Wright) which occurs in one of the limestones at Cockburnspath, a few miles south of the Thornton Burn locality (Wright, 1938, text-figs. 1–4, pls. xiii, xiv). It has, however, less rounded arms and is more distinctly biserial in the proximal region (Text-fig. 4). Above the biserial portion also the cuneiform brachials are more pronounced and continue distally with no sign of the quadrangular arrangement as seen in *A. covensis*. The cup is also distinctive in that the IB circlet is rounded and this gives a special habitus to the cup (Text-fig. 3). The pinnules are excellently preserved in the holotype and composed of eight or nine strong tapering elongate elements. The anal area in the cup of holotype is normal and well seen on the underside of specimen. The arms preserved are anterior, on left of photograph, and left anterior, on right (Plate XIII, fig. 10).



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TEXT-FIGS. 3, 4.—*Anemetocrinus wilsoni* sp. nov. from Thornton Burn, East Lothian; holotype; Text-fig. 3, anterior view of cup, showing rounded nature of IB circlet; Text-fig. 4, arm structure, as shown in left anterior ray. × 1.

Traces also of the left posterior and right anterior rays are to be seen in the specimen. There is no evidence of the ventral sac.

Since this was written, the writer has found another crown of the above species at Thornton Burn. Two of the arms are preserved undisturbed throughout their length. The strongly marked cuneiform brachials above the biserial portions persist up to the distal extremities.

Family ERISOCRINIDAE S. A. Miller, 1889

Genus **Phanocrinus** Kirk, 1937

Phanocrinus ardrossensis (Wright)

Plate XIII, fig. 8

This species is represented by two cups with fragments of arms attached. The cup figured (Plate XIII, fig. 8) is excellently preserved and is indistinguishable from similar cups that occur in the shales above the Ardross limestone in Fife, or in the shales above the limestone at Peter's Crook, in Liddesdale, Roxburghshire (Wright, 1939, pp. 24–5,

text-figs. 16, 17, pl. v, figs. 7, 8). The arms too are of the same nature, i.e. each ray branches once only on the single primibrachs, making twenty in all and the brachials are mainly quadrangular. Another characteristic in the cups of *P. ardrossensis*, i.e. the constricted anal region, is also noticeable in the Thornton Burn specimens.

Family Cromyocrinidae Jaekel, 1918

Genus **Ureocrinus** Wright & Strimple, 1945

Ureocrinus bockschii (Geinitz)

Plate XIII, fig. 6

One cup belonging to this species has been found by Mr. Wilson. It is somewhat squeezed on the anal side. The advanced structure of this region can, however, be made out, with the large RA surmounted by the two smaller X and RX plates. Probably the Thornton Burn horizon is the lowest in the Scottish Carboniferous from which *U. bockschii* has been recorded. The species has a long time range, being found in profusion in the Lower Limestone Group and high up in the Upper Limestone Group in the Muirkirk region in Ayrshire and elsewhere (Wright, 1939, pp. 28–30 ; Wright & Strimple, 1945, pp. 225–7).

Ureocrinus doliolus (Wright)

Plate XIII, figs. 4, 5

Among the Thornton Burn crinoids is a small elongated but rather flattened cup which is clearly different from *U. bockschii* (Geinitz) and comes very close to *U. doliolus* (Wright). The IB circlet is high, as are also the BB. The RR are comparatively low. Altogether the general habitus agrees well with *U. doliolus*. The anal region is of the usual advanced type of the species but in the present specimen the RA has a comparatively small connection with the LPR. This is probably just an individual variation. This species has only previously been found in the Encrinite Bed of the St. Andrews district in Fife (Wright, 1939, p. 30, pl. ii, fig. 2 ; pl. viii, fig. 12, text-figs. 31–5).

Conclusion

The Thornton Burn suite of crinoids is remarkable in several respects. First, as already mentioned, it comprises an assemblage of species not hitherto found in Scottish Lower Carboniferous rocks. Secondly, the occurrence of the rare Flexible crinoid *Talanterocrinus redesdalensis* in both the Thornton Burn and Redesdale shales and ironstones strengthens the correlation of the beds. The occurrence of the new species *Blothrocrinus thorntonensis* and *Anemetocrinus wilsoni* is also

noteworthy. *Ureocrinus bockschii* is a long lived form and it is not a great stratigraphical marker, but the occurrence of *U. doliolus* at Thornton Burn and in the Encrinite Bed at St. Andrews, Fife, may be of some significance. The occurrence also of *Phanocrinus ardrossensis* at Thornton Burn and in the Ardross section in Fife is of interest. Our knowledge of the distribution of crinoid species in the Scottish Carboniferous rocks as a whole is scanty and limited to one or two horizons about the position of the Seafield Tower Limestone of Fife, or its equivalents in other parts of the country. Comparatively few records are known above or below. Any discoveries at other levels are therefore to be welcomed and Mr. Wilson is to be congratulated on his perseverence and results in the Thornton Burn section.

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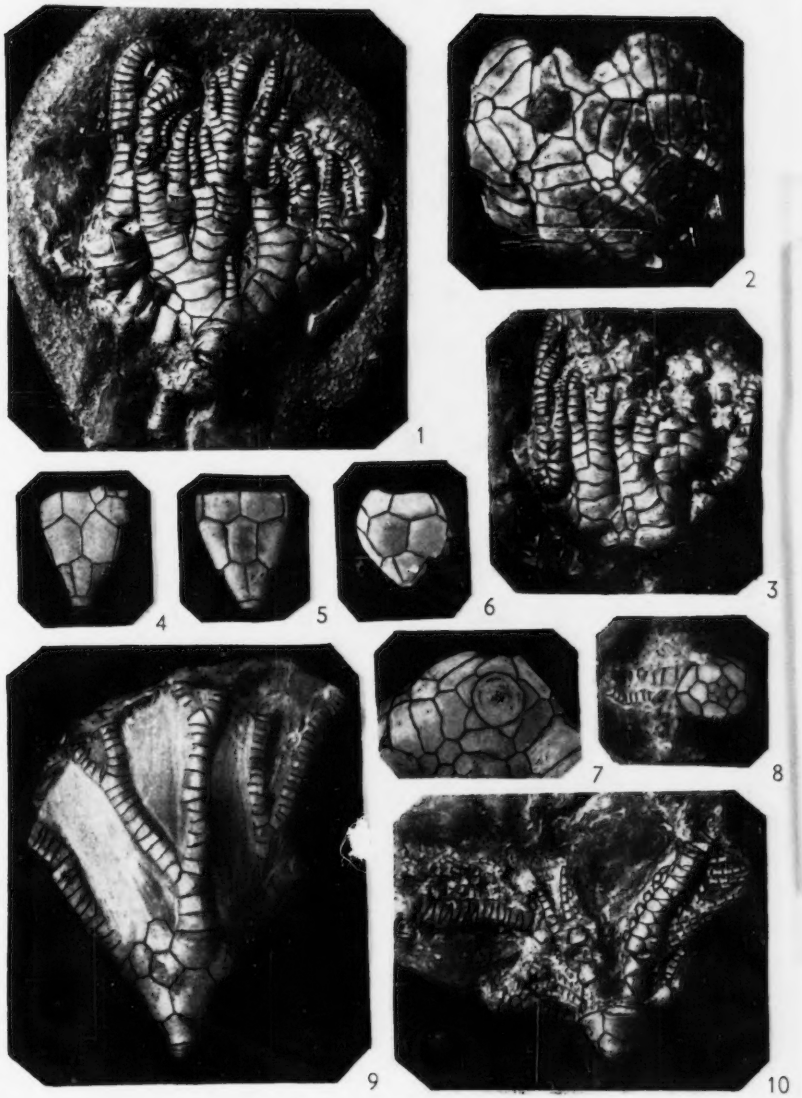
EXPLANATION OF PLATE XIII

FIG. 1.—*Talanterocrinus redesdalensis* sp. nov., Thornton Burn, East Lothian ; posterior view, showing anal tube, and left posterior ray complete ; JW2528 × 1.

FIG. 2.—*Talanterocrinus redesdalensis* sp. nov., Redesdale, Northumberland ; holotype ; basal view of crown ; Hancock Museum, Newcastle-on-Tyne ; × 1½.

FIG. 3.—*Talanterocrinus redesdalensis* sp. nov., Thornton Burn, East Lothian ; a small flattened crown from the anterior side ; JW2529 × 1.



J. Wright Photo.

CRINOIDS FROM THORNTON BURN, EAST LOTHIAN, AND REDESDALE, NORTHUMBERLAND.

FIGS. 4, 5.—*Ureocrinus doliolus* (Wright), Thornton Burn, East Lothian ; left posterior and left anterior views of a flattened cup ; JW 2534 $\times 1\frac{1}{2}$.

FIG. 6.—*Ureocrinus bockschii* (Geinitz), Thornton Burn, East Lothian ; a somewhat squeezed cup ; JW 2535 $\times$ 1.

FIG. 7.—*Talanterocrinus redesdalensis* sp. nov., Thornton Burn, East Lothian ; base of an incomplete specimen, showing the elongated posterior basal ; JW2530 $\times$ 1.

FIG. 8.—*Phanocrinus ardrossensis* (Wright), Thornton Burn, East Lothian ; cup with a few fragmentary brachials ; JW 2533 $\times$ 1.

FIG. 9.—*Blothrocrinus thorntonensis* sp. nov., Thornton Burn, East Lothian ; holotype : incomplete crown, showing three rays partly preserved ; the ray on extreme left (left post.) has two primibrachs ; the ray in centre (right post.) has three primibrachs ; JW2532 $\times$ 1.

FIG. 10.—*Anemetocrinus wilsoni* sp. nov., Thornton Burn, East Lothian ; holotype : crown showing cup and two rays partly preserved, left anterior ray on the right and anterior ray on the left ; the pinnules are well preserved and the biserial character of the proximal region of the left anterior ray is clearly visible ; JW 2531 $\times$ 1.

An Appinitic Intrusion-Breccia at Kilkenny, Maas, Co. Donegal

By W. S. Pitcher and H. H. Read

(PLATES XIV AND XV)

Abstract

An intrusion-breccia filling a pipe is made of two parts, one of facetted quartzite fragments in a granophyric matrix, the other of calc-silicate-rock fragments in an appinitic matrix. The quartzite fragments are derived from a horizon at least 1,000 ft. below the breccia level, the calc-silicate-rock fragments are local. The mechanism of emplacement of the breccia is considered to be similar to that proposed by H. Cloos for the Swabian tuff-pipes. Neither the granophyre nor the appinite of the Kilkenny pipe is regarded as of magmatic origin.

Introduction

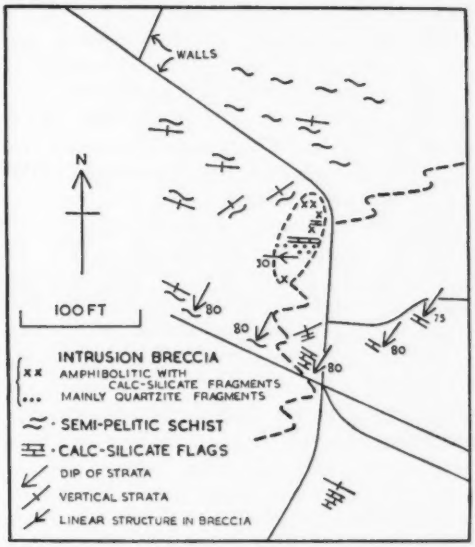
As investigation proceeds it is becoming evident that there is developed in North-West Donegal a class of varied phenomena that appear likely to supply critical evidence concerning the origin of certain lamprophyric, and especially appinitic, rocks. These phenomena are well displayed in the baronies of the Boylagh and Banagh surrounding Gweebarra Bay. Gindy (1951A, 1951B) has recently dealt with two examples. First, a sill at Tallabrista on the north shore of Gweebarra Bay, emplaced in quartzites, is charged with xenoliths of quartzite and of an amphibole-rich rock possibly derived from underlying limestone horizons; the matrix between the xenoliths is studded with large hornblende-biotite "crystals" that are most likely small fragments of basified limestone (Gindy, 1951A). Secondly, at Cor, on the northern side of the mouth of the Gweebarra River, diopside epidote and garnet skarns, together with coarse amphibole rocks, are produced at the contact of metadolerite and limestone, as the result, Gindy (1951B) suggests, of the diffusion of trondhjemitic material along the contact. At both Tallabrista and Cor, there occur rocks that closely resemble members of the appinite suite of the Scottish Highlands.

Many developments of rocks with significant and related characters have now been encountered by the Imperial College Donegal research team in the area south of Gweebarra Bay. R. L. Cheesman in Loughros, S. V. P. Iyengar in Meenalargan, and R. S. Mithal in Rosbeg have discovered xenolithic lamprophyric complexes which, though very diverse among themselves, undoubtedly belong to the class being considered here; these occurrences will be described in due course. It is the purpose of this present communication to give an account of what may well be the smallest but is certainly one of the most spectacular

of the developments, that near Kilkenny School to the north of Maas, five miles north-west of the town of Glenties.

Field Occurrence

North of the Maas-Glenties road the country-rocks are a series of Dalradian metasediments and associated metadolerite sills. The sedimentary succession of the area reaches nearly 5,000 ft. in thickness. The four lowest members of the succession, those concerned in this present discussion, are given in the table below, where is also shown the horizon of the intrusion-breccia to be dealt with here.



Text-fig. 1.—Outcrop map of a small area ¼ mile S. 10° W. of Kilkenny National School to show location of appinitic intrusion-breccia.

Maas Succession.

top	Maas Semipelitic Series . . .	600 ft.
		Horizon of Intrusion-Breccia.
	Mulnamin Calc-silicate Flag Series and metadolerite.	1,000 ft.
	Mulnamin Siliceous Flag Series . .	400 ft.
bottom	Cor Quartzite	+1,000 ft.

These rocks are tightly folded on axes running in general east and west. They give rise to a well-developed ridge and valley topography.

On the moorland ¼ mile south of Kilkenny School there is a small

but conspicuous knob of what looks at first sight like a coarse conglomerate of rounded quartzite pebbles set in a scanty matrix—this is the intrusion-breccia (Plate XIV and Text-fig. 1). It occurs at the contact of the steeply interfolded Calc-silicate Flags and the overlying Semi-pelitic Series, here andalusite-hornfelses. Detailed mapping shows that the breccia is definitely in place ; it can be extended by related types of rock beyond the very conglomeratic development, and around its margins the regular strike of the country-rocks is disturbed. The outcrop of the breccia body is oval in form, being about 30 by 12 yards.

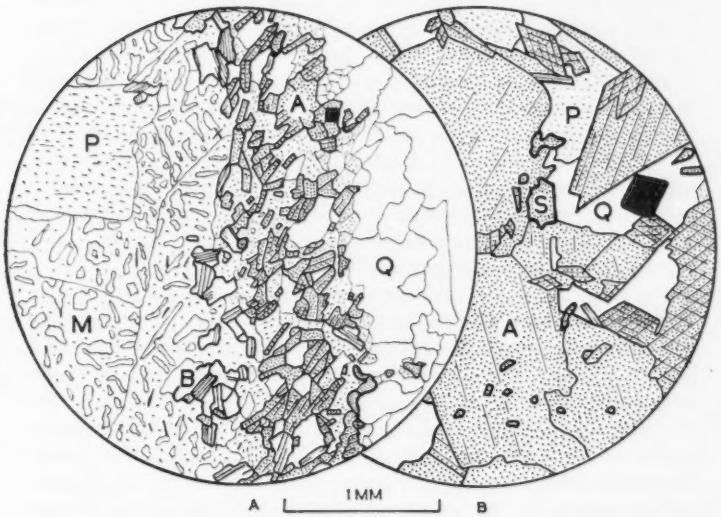
Details of the Intrusion-breccia

The intrusion-breccia consists of two main portions, a very conspicuous but minor " conglomeratic " part made of quartzite fragments in a scanty matrix and a less conspicuous major part formed of a hornblendic rock containing fragments, dominantly of calc-silicate flags but including a few of quartzite. The distribution of these two parts is indicated in Text-fig. 1 ; the quartzite-breccia is roughly central in the body. They may be described separately in more detail.

The Quartzitic Breccia.—The typical aspect of the quartzitic breccia is seen in Plate XIV. It consists of closely packed white quartzite " pebbles ", set in a darker fine-grained matrix. The largest of the quartzite pieces is about 5 in. in length, their average length being 3 in. The rock from which they were derived was evidently bedded so that the fragments to a certain degree have a slabby form ; typical dimensions might be 1 × 2 × 3 inches. A few of the fragments show a banding that can be taken as of sedimentary origin ; the banding shows that the fragments are disorientated. These slightly slabby pieces are arranged in planar fashion, the planation dipping nearly vertically southwards ; in addition their longest axes show a fairly good alignment, giving a lineation plunging at 30° to the west in the plane of the slabs. The quartzite fragments are subrounded, or well-rounded with smooth and often striated surfaces. Many of them are spindle-shaped and some closely resemble dreikante in form (see Plate XV, lower). In general, they have shapes reasonably interpreted as due to attrition. All the quartzite fragments are coated with a continuous thin skin, no more than 2–3 mm. thick at the most, of blackish-green ferromagnesian material (see Plate XV, top). The dark rims completely surround the banded fragments and show no differences against different bands in the fragments. Whilst most of the " pebbles " are of quartzite there are a few of dark-coloured calc-silicate-rock ; these are well rounded and are similarly coated as illustrated in Plate XV top right.

The petrography of the fragments and matrix of this quartzitic breccia is now given. In thin slices, the *quartzite* fragments are seen

to be almost entirely composed of interlocking quartz grains of a fairly uniform size and often with a lenticular shape ; occasionally small patches of finer quartz grains are seen. Accessory components of the quartzites are turbid felspar grains, yellow-green chlorite after biotite, calcite as a rare patchy cement to quartz grains and cubes of pyrite. Banded " pebbles " are found to be composed of alternations of quartzite, quartz-felspar-granulite, and impure calcareous quartzite, this now being represented by a quartzite with scanty interstitial olive-green biotite and pale greenish amphibole ; pyrite is a common



TEXT-FIG. 2.—Intrusion-breccia. (A) Contact of quartzite fragment with granophyre groundmass showing the intervening mafic rim. (B) Appinitic portion. A, Amphibole, M, Micropegmatite. P, Plagioclase. Q, Quartz. S, Sphene. Black cubes represent pyrite.

accessory in such bands. The *black rims* to quartzite and banded quartzite alike are made of a confused mixture of hornblende, biotite, chlorite after biotite, sphene, and grains of granophyric quartz and acid plagioclase (Text-fig. 2A) ; other diffuse patches of similar material occur in the matrix of the breccia—these may be chance sections entirely in the rim and not penetrating the associated fragments. The rare *calc-silicate* fragments consist of a felt of a light green acicular amphibole associated with scanty granules of calcite. A greenish biotite appears abundantly in the slightly darker rim.

The *matrix* of the quartzitic breccia is coarse-grained and patchy. Its main constituent is a granophyric association of quartz and acid

plagioclase in large interfering units which often have at their centres almost solid oligoclase crystals of euhedral shape ; the resulting texture is similar to that shown by many markfieldites. In the granophyre areas there are commonly separate quartz grains or aggregates of a few grains that are clearly derived from quartzite fragments. The dominant ferromagnesian mineral is biotite, in colourless to yellowish brown or greenish laths, often rudely clotted ; amphibole appears to be absent or very rare in the true granophyric areas. Conspicuous accessories are sphene in tiny granules often arranged in patterns of chains or grids, apatite in very long slender needles spearing through several granophyre grains, and pyrite. In the typical granophyric matrix there occur appinitic patches, somewhat similar to the matrix of the calc-silicate breccia described immediately, but often containing granophyre grains. A matrix intermediate in composition between granophyre and appinite is found to corrode and replace to a small extent certain of the quartzite fragments. At the centre of the east side of the intrusion-breccia body there is found adhering to the quartzite-breccia what appears to be *wall-material* ; this is an equigranular hornfels made up of quartz, calcite, amphibole, and deep brown biotite.

The Calc-silicate Flag Breccia.—As already noted, the major part of the breccia body is made of a hornblendic rock containing calc-silicate flag fragments which forms lower ground than the quartzitic breccia. This hornblendic part varies in belts trending east and west. Immediately north of the quartzitic breccia there is found a narrow, fairly continuous band of dense calc-silicate-rock, in many respects similar to the calc-silicate flags of the Mulnamin Series. Elsewhere, the hornblendic rock contains numerous enclosures of calc-silicate-rock accompanied, in places, by scarcer quartzite fragments like those of the quartzitic breccia. The calc-silicate fragments are generally small or rather slabby ; they can be distinguished from the hornblendic matrix by their finer grain and lighter colour.

Under the microscope the components of this portion of the breccia present the following features. The *matrix* is a coarse association of amphiboles with a small proportion of plagioclase and quartz (Text-fig. 2B). The amphiboles vary in colour from almost colourless to medium green and form large plates with irregular interfering edges against one another, but with idiomorphic outlines against the felspar. These plates are often colour-zoned but with no consistent order—dark rims to lighter cores and the reverse can be observed. They are full of tiny dark inclusions. The less abundant felspar occurs as turbid areas along with quartz interstitial to the amphibole plates—so far as can be determined, it appears to be an intermediate plagioclase. A very small amount of deep brown biotite

is seen to replace the amphibole in some slices. Sphene granules are common and irregular masses of pyrite are conspicuous in this matrix. The rather slabby fine-grained *calc-silicate* fragments enclosed in this matrix are found on slicing to be fine-grained aggregates, consisting largely of amphibole with less diopside, set in a base of granular quartz and sodic plagioclase. Various proportions of acicular amphibole and granular pyroxene form the bulk of other fragments, in which calcite sometimes forms a minor constituent. Pyrite is abundant in disseminated small grains.

Discussion

From the nature and field-relations of this breccia body it is clear that it is intrusive—this, of course, carrying no implication whatever of igneous or magmatic activity. If it ever reached to the surface it could be described as a vent-filling; in the circumstances it may best be called an intrusion-breccia. We may inquire into the sources and production of its several components.

Our knowledge of the local Dalradian succession enables us to make proposals concerning the *sources of the fragments*. The calc-silicate fragments are exactly similar to rocks making up large parts of the immediately adjacent Mulnamin Calc-silicate Flag Series. This series, with its associated metadolerite, is as previously mentioned about 1,000 feet thick; the present exposed level of the breccia is at the extreme top of the series. The movement of the calc-silicate blocks in the breccia need, therefore, be very small but, on the other hand, it may be at least 1,000 feet and very much more if the breccia has pierced inclined beds. The distance moved by the calc-silicate fragments cannot, therefore, be determined, but certain suggestions can be made concerning the quartzite fragments. It is reasonable to consider these to be derived either from the Cor Quartzite, the top of which is stratigraphically 1,400 feet below the top of the Mulnamin Calc-silicate Flag Series, or from the Siliceous Flag Series immediately above the Cor Quartzite. A figure of a thousand feet is the minimum distance that the quartzite blocks can have travelled, unless there are unknown tectonic gaps in the sequence of the Kilkenny area. If there are no such gaps and since the beds are not horizontal and since, moreover, the "vent" may not have been drilled vertically, then it is possible that the quartzite fragments have travelled much more than a thousand feet—they may have come several thousand.

The quartzite fragments, though coming from a slab-making rock and one breaking with sharp corners and edges, have rounded or subrounded spindle and dreikante shapes. Like the similarly shaped pebbles of sediments, they are clearly the result of the attrition of originally angular fragments in a moving medium of some kind. We may envisage a body of quartzite blocks, lubricated by a scanty

medium, rushing violently thousands of feet up an opening pipe. At the stratigraphical level at which we now see them, the exotic quartzite blocks with blocks of the local calc-silicate rocks reached a position of equilibrium in the uprising medium. In this stable position, consolidation of the medium took place with the formation of the intrusion-breccia. If we had suitable data on the densities of the quartzite and calc-silicate blocks and if we were skilled in the mathematics of elutriation, we might be able to calculate what the physical characters of the transporting medium were likely to have been ; in some circumstances, however, intuition is as good as arithmetic.

This mechanism is similar to that proposed by Hans Cloos (1941) for the explanation of the tuff-pipes of Swabia, an explanation recently applied by D. L. Reynolds (1951) to the intrusion-breccias and associated phenomena seen in the Tertiary complex of Slieve Gullion in Ireland. In his masterly fashion, Cloos demonstrated that the blocks of Jurassic limestone in the Swabian tuff-pipes had *sunk* from their original country-rock position through the ascending mixture, lubricated by hot gases, of solidified lava-drops and splinters of country-rock that eventually reached the surface. In her discussion of the transgressive granophyres and hybrids of Slieve Gullion, D. L. Reynolds (1951, especially pp. 114–130) pictured the rising of gas streams, carrying detached particles, up fissures ; inclusions may be balanced in such rising gas streams and remain at the same horizon, together with heavier fragments that sank and lighter ones that rose. She goes on to say (loc. cit., p. 130) : " The rounding of the inclusions is attributable, not to magmatic corrosion, but to abrasion within the gas-tuff streams comparable to the abrasion of pebbles by sandblast under desert conditions and analogous to the attrition of pebbles in a river bed." These concepts of Cloos and Reynolds exactly fit the Kilkenny intrusion-breccia.

H. B. Muff (1908, p. 119) mentions a small lamprophyre dyke emplaced in the quartzite of Glen Creran, Argyllshire. It is so thickly studded with quartzite fragments as to resemble a breccia. The fragments are both rounded and angular and presumably " represent portions torn from the wall of the fissure, and carried upwards ".

Ogden Tweto (1951) has recently described intrusion-breccias accompanying porphyrite sills near Pando, Colorado. The advance of certain sills is preceded by the explosive introduction of fluids or tenuous magma ; one sill is " literally blown into place " (loc. cit., p. 527, fig. 16). The presence of Pre-Cambrian rock-fragments in such a sill at a horizon several hundred feet above the basement rocks suggests that the sill was " emplaced explosively " (loc. cit., p. 528).

Brecciated country rocks occur at the margin of the syenite-hornblendite intrusions in Kiloran Bay, Colonsay, Scotland, where they

were first described by W. B. Wright (1911, p. 29), and later investigated in detail by D. L. Reynolds (1936). These breccias consist of fragments of the phyllites forming the wall rock, quartzite, and rarer limestone. They are interpreted as being produced by " magma pressure ", the latter two types being brought up from below. Quartzite blocks in the breccia are sometimes rounded ; they were considered by Wright to be water-worn pebbles that had fallen into the fissure but Reynolds held that they had been rounded by magmatic attack. Dark rims surrounding some quartzite fragments were due to a concentration of the original ferromagnesian constituents of the quartzite swept inward during progressive felspathization of the margin.

We may now consider the origin of the matrixes of the Kilkenny intrusion-breccia. There is an obvious relation between the nature of the matrix and the dominant xenolith. The granophyric matrix is associated with quartzite fragments and in it are relics of quartzite and of quartz grains ; the appinite matrix is associated with calc-silicate fragments. We suggest that the two matrixes are predominantly made of re-constituted quartzite and calc-silicate-rock respectively. This material has been comminuted in the pipe by the attrition of the fragments in the uprushing fluid and has been drenched and soaked by it. When solidification in the pipe occurred, the products were granophyre and appinite. On this interpretation, the attrition has been most effective at the present position of the breccia in the pipe. It seems unlikely that magma in any usual meaning of the term has been involved—the correlation between fragments and matrix is too close. We propose that a sodic fluid, probably gas-charged, was the operative medium.

The formation of the black amphibole-biotite rims to the quartzite pebbles is a matter of much interest and difficulty. These rims, completely coating the dreikante-like pebbles, must have been produced after attrition had ceased—otherwise they would have been rubbed off in certain places. Their formation is, therefore, either part of the solidification phenomena or a later event. They do not appear to us to be due to a replacement of the quartzite material ; we can recognize corrosion of fragments (as illustrated in Plate XV, top), and have determined it to be small and local—most of the pebbles are not corroded at all. Further, any considerable corrosion of banded pebbles should surely be selective—there is no sign of this in our material. The rims are unlikely to be either basic fronts or basic behinds ; most of the quartzites have insufficient ferromagnesian components to supply either, and the rims form an even skin of nearly constant thickness to all parts of the banded fragments. They appear to be mere coatings on the shaped pebbles deposited during the " setting " of the fluid in the pipe. We do not know whether this coating is the

result of a limited surface reaction or precipitation due to some kind of differentiation during setting. In any event, though of great interest in themselves, the rims are of trifling volume in the contents of the pipe as a whole.

From our Donegal experience we have found appinitic rocks to be genetically associated with calc-silicate-rocks. Just as one of us thinks there may be granites and granites, so there may be appinites and appinites—we can but wait and see. The appinites are grouped with the lamprophyres and the whole group seems notoriously prone to hybridization, contamination, and all kinds of processes that are not consonant with straight crystal-fractionation differentiation. Perhaps as the investigation proceeds in Donegal, there may become available evidence that will settle the origin of some members, at least, of the group. Geologists who have to deal with the hornblendic lamprophyres may care to consider, even though they dismiss, these proposals. Granophyres and appinites may not all be magmatic and igneous.

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EXPLANATION OF PLATES XIV AND XV

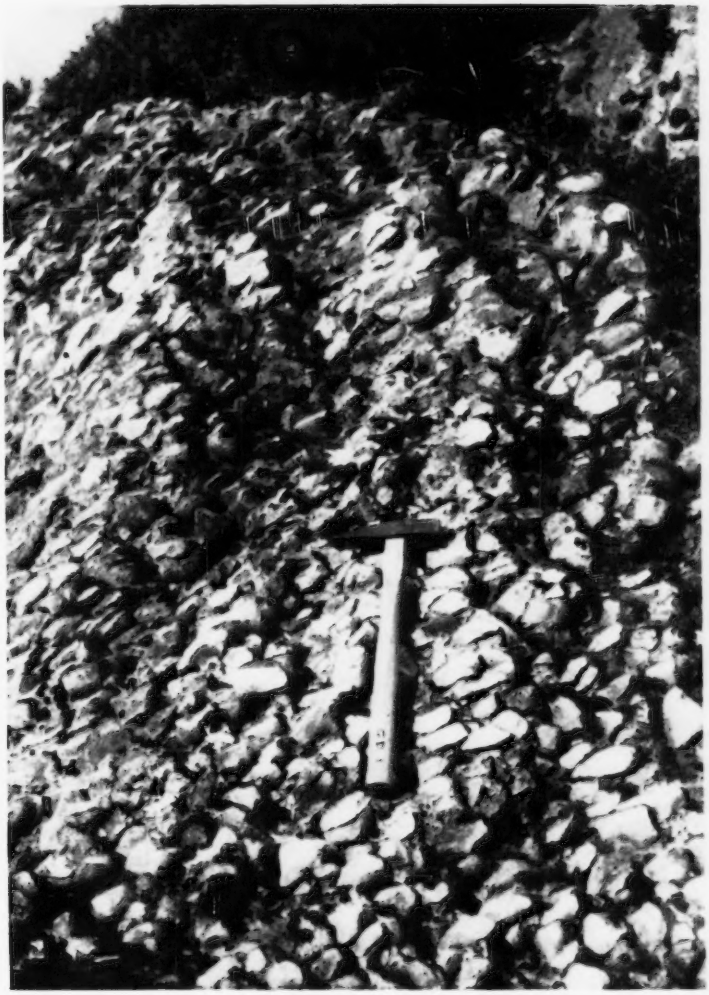
Plate XIV

Intrusion-breccia, Kilkenny. White quartzite fragments predominate in a matrix of greyish granophyre. The slabby fragments are arranged in a planar fashion and their longer axes are crudely aligned.

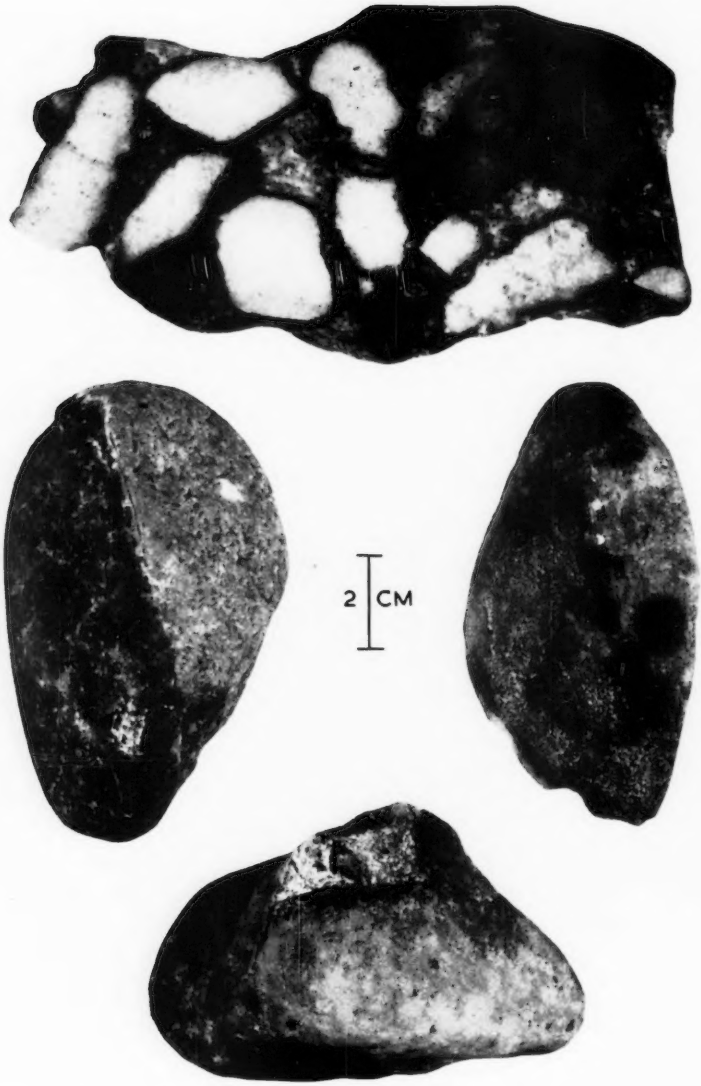
Plate XV

Top: Polished Slab of intrusion-breccia showing the narrow black rims around the quartzite fragments. A fragment of calc-quartzite appears in the top right and part of another entirely composed of calc-silicates lies immediately above it.

Bottom: Three dreikanter-like fragments are shown separated from their matrix, a portion of which remains attached to the lower example.



INTRUSION-BRECCIA, KILKENNY.



POLISHED SLAB OF INTRUSION-BRECCIA AND EXAMPLES OF DREIKANTER-LIKE FRAGMENTS.

Mugearites and Oligoclase-Basalts

By Frederick Walker

Abstract

The use of the term mugearite as a synonym for oligoclase-basalt is discussed. It is shown that the two rock-types, though often agreeing closely in chemical composition, may differ appreciably in their fabric and mineralogy.

Introduction

THE olivine-basalt—trachyte associations of oceanic islands frequently include transitional types which are difficult to classify and the author has recently encountered such a case in the island of Mauritius. An analysed lava has the chemical composition of a mugearite but differs from mugearite considerably in its mineralogy and general aspect. This raises the question of the suitability of the term mugearite for oligoclase-basalts which show only moderate resemblance to the type rock from Mugeary, Skye (Harker, 1904).

The Type Mugearite

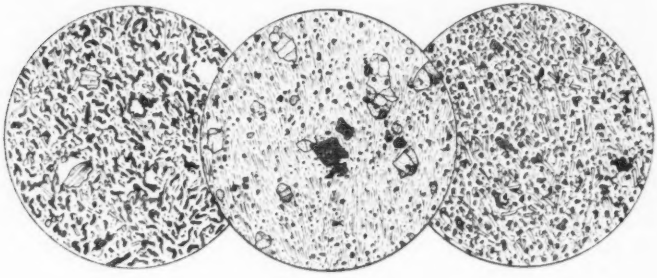
The type mugearite of Druim na Criche near Mugeary, Skye, was thought by Harker (1904, p. 257) to be the lowest member of a composite sill but strong evidence that it is part of a composite lava flow has been given by Kennedy (1931, p. 179). The rock is characterized in the field by marked fissility and yellowish-brown colour on outcrop. The special features of the chemical analysis compared with the average Hebridean olivine-basalt (" plateau-basalt " of Mull Memoir) are relative richness in Na_2O, K_2O, SiO_2, and P_2O_5, with relative poverty in CaO and MgO. The type rock belongs to the essexitic magma-type of Niggli.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
Type mugearite Druim na Criche	50·5	16·3	6·2	7·4	3·1	5·4	5·3	2·3	1·9	1·6
Hebridean olivine-basalt (7 analyses)	47·6	15·7	3·7	9·2	8·5	10·2	2·1	0·6	2·2	0·2

Table I.—Composition of Type Mugearite and Average Hebridean Olivine-basalt (100 per cent water-free)

Microscopically the rock shows well-marked fluxional arrangement of oligoclase laths mantled by orthoclase. Microphenocrysts of fresh olivine are abundant but augite is quite subordinate. Iron ore and apatite are both present in large amount and small flakes of a brown mineral (later identified as biotite and hornblende by Flett, 1908) are conspicuous.

The mode of the type mugearite as given by Harker is : Oligoclase 57½ ; orthoclase 12½ ; olivine, iron-ore, and augite 26½ ; apatite 3½. A micrograph of this rock is given by Harker (1936, fig. 66), and is reproduced in Text-fig. 1.



TEXT-FIG. 1.

A. Mugearite, Druim na Criche. Marked trachytic structure. Microphenocrysts of olivine. Ore in sparse larger grains.
B. Oligoclase-basalt, Mauritius. Less perfect trachytic structure. Microphenocrysts of hornblende. Ore in abundant small grains bunched in elongated groups.
C. Oligoclase basalt, Hawaii. Less perfect trachytic structure. Ore in smaller and more abundant grains.

All × 15.

SUBSEQUENT HISTORY OF THE TERM MUGEARITE

Although the type mugearite has a distinctive mineralogy, Harker extended the term to cover rocks with much less olivine and apatite but considerably more biotite and hornblende. In all these varieties, however, fluxional oligoclase mantled by orthoclase is the dominant constituent, iron ore being abundant and augite subordinate. An example is figured by Harker (1908, plate vii, fig. 2A).

Following on Harker's Hebridean work mugearites were found to be a fairly common type amongst the Carboniferous lavas of the Midland Valley of Scotland. Although they are more altered than the Tertiary examples from the Hebrides, they agree with them closely in chemical and mineralogical composition. Full descriptions with chemical analyses have been given by Flett (1908, p. 119 ; 1910, pp. 322–3), Bailey (1910, pp. 123–4 ; 1911, pp. 140–3), MacGregor (1930, pp. 105–108), and Kennedy (1933, pp. 87–8). Campbell and Lunn (1927, pp. 489–505) have described a series of saturated, alkaline dolerites and tholeiites forming sills west of Edinburgh and believed by the authors to represent the sub-surface equivalent of the neighbouring mugearite plateau lavas of Corston Hill.

Further work in the Hebridean province has revealed the presence of mugearites in the lavas of Mull and Ardnamurchan (Bailey, 1924, pp. 143–5 ; Richey, 1930, p. 353).

Use of the term mugearite is not frequent outside British literature. Lacroix (1936, p. 223) has compared an " andésite oligoclasique " from Réunion to mugearite but this is a transitional type to trachyandesite both chemically and mineralogically (Text-fig. 2).

Benson and Turner (1940) have described examples from Dunedin with two chemical analyses (see Text-figs. 2 and 3) and these rocks may be accepted as true mugearites by all criteria.

The oligoclase andesites of the Hawaiian group have given rise to considerable discussion on points of nomenclature and it has been suggested more than once that they have affinities with the mugearites (Washington, 1923, p. 472 ; Tilley, 1950, p. 46). Some of the oligoclase-basalts of Central Victoria also resemble the mugearite group but are distinguished from it by a higher potash content with corresponding richness in orthoclase (Edwards, 1938, pp. 272–3).

Turning to some well-known petrological textbooks which mention mugearite we find considerable differences in the criteria used to define the type. These criteria are presented below in tabular form together with those used by Harker, Flett, Bailey, and MacGregor when dealing with the original Scottish examples.

Discussion of Classification Data for Mugearite and Oligoclase Basalt

Table 2 makes it clear that much confusion exists over the use of the term mugearite and that there is need for clarification. Opinion is divided on the matter of classification but five of the eleven authors, dealing with this, group mugearite with trachydolerite or trachybasalt. There is little justification for placing mugearite amongst the andesites, for it is a basic rock with basaltic associations.

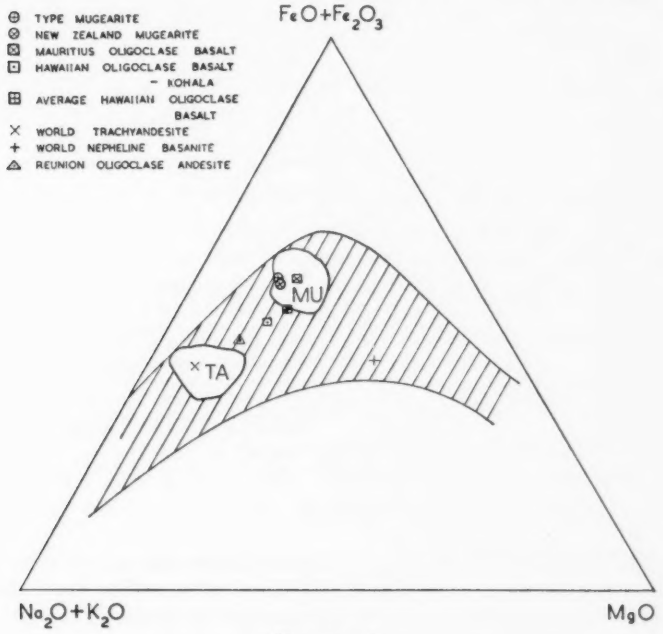
With regard to the other data, it has in some cases proved difficult to adjust a qualified statement to tabular form, but there is a clear majority of those who consider mugearite to be an aphyric to microphyric rock with fluxional oligoclase with subordinate orthoclase and olivine as the main constituents. Those who have had field experience with the type emphasize its conspicuous colouring on outcrop and its fissility, probably due to fluxional feldspar.

The chemical characteristics of the mugearites proper are quite definite. When the eight available analyses of normal Scottish mugearites are plotted on a variation diagram with MgO, $FeO + Fe_2O_3$, $Na_2O + K_2O$ as co-ordinates, they fall in a small compact field (MU in Text-fig. 2). A plot of SiO_2 against $Na_2O + K_2O$ shows a similar result (Text-fig. 3). The mugearite field is far removed from the

Author	Classification								Mineral Constituents (M) Major (S) Subordinate								Fabric (P) Phyric (p) Microphyric			Other Criteria	
	Trachydolerite or trachybasalt	Soda basalt	Oligoclase basalt	Oligoclase andesite	Andesine basalt	Andesite	Olivine andesite	Trachyandesite or trachyte-andesite	Oligoclase	Oligoclase to andesine	Orthoclase	Olivine	Iron ore	Augite	Hornblende and biotite	Apatite	Aphyric	Aphyric to microphyric	Trachytic or fluxional	Fissile	Yellow weathering
Harker, 1937		+								M	M	M	M	S		S	+	p	+	+	
Hatch & Wells, 1949	+								M			M						p	+		
Holmes, 1920									M		M	M		S					+		
Shand, 1947		+							M		M	M	S	S		S	+				
—— 1948			+						M		M	M	S	S		S					
Tyrrell, 1948	+								M		M	M	M	M							
Iddings, vol. ii, 1913				+					M			M						p			
Johannsen, vol. i, 1948								+				M									
—— vol. iii, 1937								+	M		M	M	S	S	S	S			+		
Turner & Verhoogen, 1951					+				M												
Wahlstrom, 1947						+			M		M	M		M					+		
Rosenbusch, 1910	+								M		M	M	M	S		S		p	+	+	+
Troeger, 1935							+		M		M	M	S	S		S			+		
Bailey, 1910	+								M		M	M	S	S	S	S	+	P	+	+	
Flett, 1910									M			M	M	S	S		+	p	+	+	
Harker, 1904									M		M	M	S	S	S	S	+	p	+	+	+
Macgregor, 1930	+								M			S	M	S	S	S	+	p	+		

Table 2.—Criteria used for the Classification of Mugearite

field of Scottish trachyandesites as represented by six analyses (TA, text-fig. 2). Scottish trachybasalts have a distribution too much scattered to give a satisfactory field but all are far removed from the mugearite field of Text-fig. 2. Daly's world average for nepheline-basanite lies near the middle of the group. The field for all the Carboniferous lavas and co-magmatic intrusions is also shown in Text-fig. 2, and it is noteworthy that the mugearite field is near but just beyond

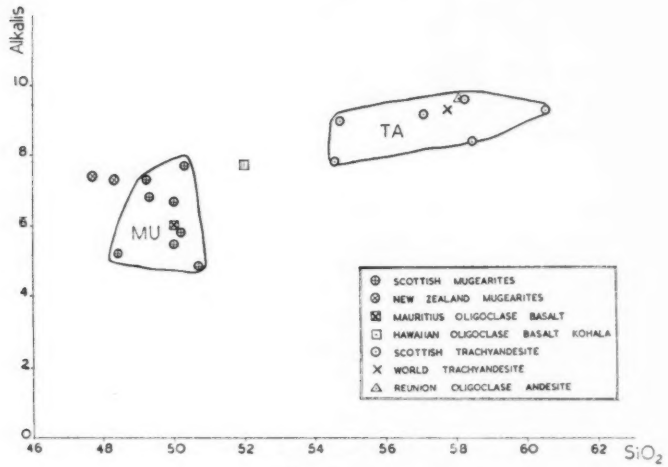


TEXT-FIG. 2.

the peak of iron enrichment in the differentiation trend. It is possibly significant that the mugearites proper appear to be confined to sialic basaltic provinces.

The rock which raised the classification question for the author is a dense black aphyric type of basaltic appearance from the Old Lava Series of Mauritius (Simpson, 1951). In the hand specimen this rock bears little resemblance to either the Tertiary or the Carboniferous mugearites of Scotland. Under the microscope it appears to be considerably richer in iron-ore than the type rock of Druim na Criche or any other Scottish mugearite though it will be shown later that this appearance may be deceptive. Apart from rare possible pseudomorphs

in iddingsite olivine is absent. Fluxional arrangement of the oligoclase laths is less marked than in the Scottish rocks but there is a tendency for the small ore grains to become aligned in elongated groups parallel to the feldspar. Orthoclase is inconspicuous but biotite and hornblende form the largest crystals in the rock. The type has a thoroughly basaltic aspect in the hand specimen and under the microscope. It is almost certain that no Scottish petrologist would call the Mauritius rock a mugearite.



TEXT-FIG. 3.

In spite of these differences, which are clearly seen in the micrographs of Text-fig. 1, the plot of the Mauritius lava in Text-fig. 2 falls very close to that of the type mugearite and well within the Scottish mugearite field. The analysis of the Mauritius rock is given in Table 3 with that of the average Scottish mugearite for comparison. Objective observers, familiar with rock analyses, failed to select the Mauritius analysis from the group of eight Scottish mugearite analyses used to calculate the Scottish average (Guppy, 1931, analyses 299–306).

The author is greatly indebted to Dr. G. A. Macdonald for very kindly furnishing specimens of Hawaiian lavas. These show that the Mauritius rock closely resembles an " oligoclase andesite " (oligoclase-basalt of this article) both in the hand specimen and under the microscope (Text-fig. 1). The chemical analysis of this Hawaiian lava, and also the average of eleven analyses of Hawaiian oligoclase-basalts, show excellent agreement with those of the Mauritius rock and of Scottish mugearites (Table 3 and Text-fig. 2).

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
Average Scottish mugearite (8 analyses) . .	51·7	16·2	6·0	6·6	3·6	6·2	4·6	2·0	2·4	0·7
Oligoclase-basalt Mauritius * . .	51·1	15·5	6·6	5·6	3·5	7·6	4·3	1·8	3·4	0·6
Oligoclase-basalt Kohala, Hawaii	51·7	16·2	2·8	7·4	3·2	6·7	5·6	2·1	3·0	1·3
Average Hawaiian oligoclase-basalt † . (Macdonald, 1941, p. 87)	51·7	16·4	4·7	6·2	3·7	6·6	5·0	1·9	2·8	1·0

* Analyst : W. H. Bennett. † Analyst : H. S. Washington.

TABLE 3.—ANALYSES OF MUGEARITES AND OLIGOCLASE-BASALTS (100 PER CENT WATER-FREE)

To sum up : *The Mauritius and Hawaiian oligoclase-basalts, though very close to the Scottish mugearites in chemical composition, have a thoroughly basaltic appearance both in bulk and in thin section in contrast to the definitely trachytic aspect of the mugearites.*

There seem to be three reasons for the different appearance of the two rock types :

(1) Trachytic structure is more perfect in the feldspar of the mugearites.

(2) The small size of the ore grains in the oligoclase-basalt gives a false impression of the abundance of this constituent in thin section and tends to mask any trachytic structure which may be present.

(3) The abundant small ore grains of the oligoclase-basalts impart a dark appearance to the hand specimen.

The second of these reasons is probably the most important. The Hawaiian oligoclase-basalt contains only 5·8 per cent of $Fe_2O_3 + TiO_2$ against 8·1 per cent in the type mugearite. Since augite, in which these oxides might enter, is quite subordinate in both rocks, the mugearite might be expected to contain a greater proportion of ore, but in thin section (Text-fig. 1) the reverse appears to be the case. This is almost undoubtedly due to the very small size of the ore grains in the Hawaiian rock which average only 0·012 mm. in diameter. The ore grains in the mugearite are much larger, some of them attaining a diameter of 0·4 mm. Text-fig. 1 probably underestimates the darkening and masking effect of the ore in the oligoclase-basalts, for in order to clarify the microstructure the thin sections were ground abnormally thin ($< 0·02$ mm.) In sections of normal thickness the wedge effect and general opacity caused by the iron ore is so great that details of

microstructure are lost. This is especially so with the Mauritius rock where the percentage of $Fe_2O_3 + TiO_2$ reaches 9·8, indicating a great actual abundance of ore.

No reason was found for the poverty in olivine of the oligoclase-basalts, except perhaps their greater abundance of biotite and hornblende, nor for the different habit of the iron ore.

Suggestions as to Nomenclature

The above evidence has led the author to suggest, with some diffidence, the following criteria for the nomenclature of oligoclase-basalts and mugearites :—

(1) The term oligoclase andesite should be abandoned, since rocks described under that name are basic and have basaltic associations.

(2) The term mugearite should denote a fine-grained aphyric or microphyric rock rich in oligoclase, fissile, and brightly coloured on outcrop, and with well-marked trachytic feldspar laths in thin section. Less abundant major constituents are orthoclase, olivine, and iron ore. Augite is subordinate in amount, biotite and brown hornblende generally present, and apatite an abundant accessory. The general aspect is trachytic.

(3) Any rock which agrees in chemical composition with the mugearite group, but has a basaltic appearance, should be named oligoclase-basalt.

It is believed that these suggestions, although somewhat restricting the use of the term mugearite, would clear up most of the difficulties in classifying a well-defined compositional group.

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New Evidence on the Correlation of the Lower Carboniferous Reefs at Castleton, North Derbyshire

By Trevor D. Ford

Abstract

There are two alternative hypotheses regarding the relationship of the goniatite-bearing reef limestones to the coral-bearing "massif" limestones. One claims an unconformity between the reefs and bedded limestones, the other a lateral passage from a "massif facies" to "marginal facies". Surface exposures are such that it is difficult to be convinced of either hypothesis. Details of underground exposures in natural cave systems and associated mine-workings show a clear transition between facies and no trace of unconformity.

Introduction

THE Carboniferous Limestone of the Castleton area in North Derbyshire is represented by two facies: marginal reef and massif. The latter is generally well-bedded with dips rarely exceeding 15°, and has been assigned to the coral-brachiopod zones S_2, D_1, and D_2. The marginal reef limestones have poorly developed bedding, generally of a lenticular nature, with dips commonly of 30° or more, and are represented by a reef belt which rarely reaches half a mile in width. Dips are generally outward from the massif, although some promontories develop quaquaversal dips. These reef limestones have been assigned to the goniatite zones B_2 and P_1. A small area of basin facies limestone of later P age occurs in Castleton village. All three facies are overlain unconformably by the Edale Shales, the basal beds of the Millstone Grit Series (Jackson, 1925).

The interrelations of massif and reef facies limestones have been the subject of much controversy since Shirley and Horsfield suggested (1940) that the reef limestones rested unconformably against cliffs of massif limestones, i.e. that the B_2 goniatite zone post-dated the D_2 coral zone. The main evidence for this unconformity was obtained from three widely spaced exposures of which only one undoubtedly shows poorly bedded limestone resting unconformably on limestone with better developed bedding, and which, in part, contains D_1 corals and brachiopods. Corals and brachiopods of zonal value in the massif succession are rare in the reefs, and Shirley and Horsfield claimed that they were derived from the massif facies limestones and incorporated in the "sub-marine screes" of the reefs.

An alternative interpretation was advanced by Parkinson (1943 and 1947) in which he considered that the reefs were the lateral equivalent of the massif limestones, i.e. that B_2 was approximately equivalent to D_1 and P_1 to D_2. He pointed out that local unconformities were to be expected in any reef which had been subjected to

periodic wave erosion such as was shown by the rolled shells of the beach beds. He also described a number of exposures of passage beds which could be grouped with either reef or massif facies. The " derived fossils " could not be shown to have any adherent matrix differing from the surrounding reef limestone, nor did they show much evidence of erosion. Moreover it appeared to be possible to trace certain characteristic beds, such as tuffaceous breccias, from one facies to the other. Palaeontological evidence from other parts of the country tends to support Parkinson's hypothesis.

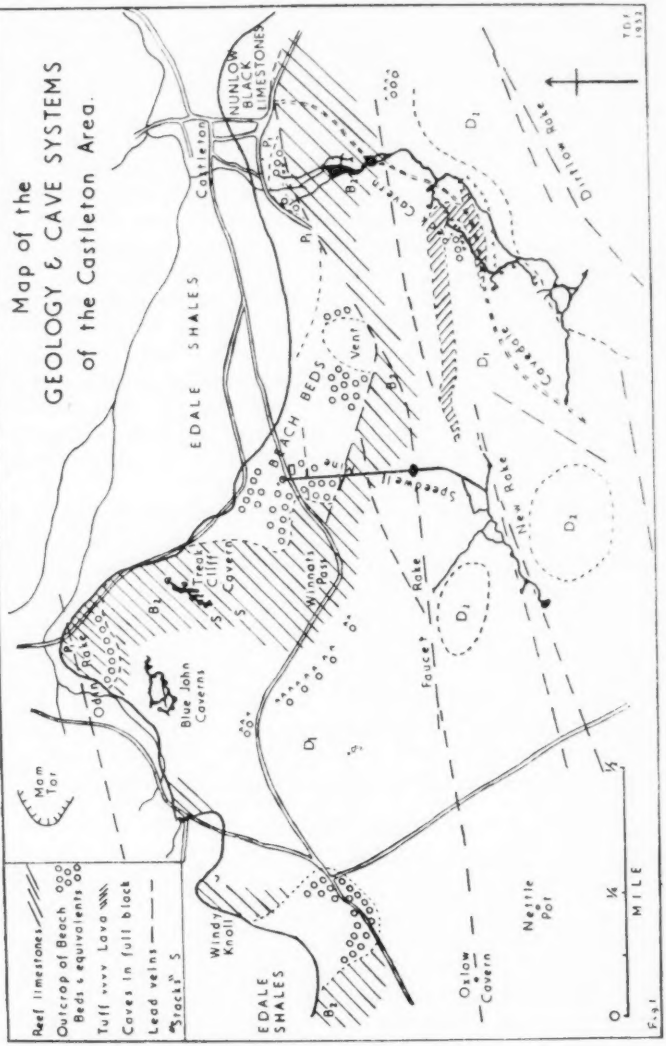
Surface exposures around Castleton do not enable a convincing demonstration of either hypothesis to be made, for the lack of exposures or the presence of minor faults often obscure the relationship between reef and massif facies over much of the area. The previous workers in this area were entirely concerned with the surface exposures, and paid no attention to the wealth of underground exposure which characterizes the neighbourhood. The present work is concerned with the entire evidence available and in particular with that part of it which is revealed by underground exposures. This new evidence, obtained during an investigation of the subterranean drainage systems, throws much light on this controversial problem. The writer considers it may be decisive in establishing the true relationship between the marginal reef and massif facies deposits and in effecting their correlation.

Castleton is well-known for the four caves which have been developed as tourist attractions. Three of these present continuous sections in the critical portions of the reef and two continue into the massif facies. If an unconformity existed between the facies it would be cut through by these caves, and the boulder beds, inseparable from the presumed cliff topography should be clearly visible. The positions of the cave sections relative to the surface geology are indicated on the accompanying map (Text-fig. 1). Detailed collecting has not been possible in every case as some parts of the sections have been examined while standing waist deep in cold water and in others the owners of the caves have been unwilling to allow disfiguration of their property.

Peak Cavern

For a full understanding of the section in the cavern that in the gorge outside is included. On the east side of the entrance to the gorge two small quarries above the Russet Well are in Beach Beds, somewhat mineralized, and underlain by a greenish clay, a decomposed tuff which Parkinson (1947) has suggested may be correlated with that seen in the massif facies in Cavedale about 30 feet above the lava. The contact of these beds with the underlying reef limestones is not seen, but there is probably a local unconformity since there is a marked

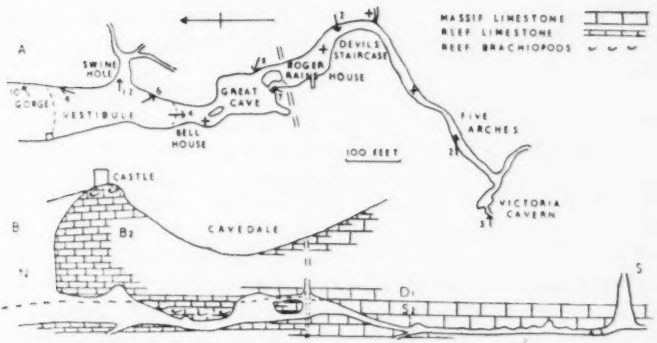
decrease in dip on passing from reef limestones to beach beds. The remainder of the gorge presents an unbroken section in reef limestones, by far the greater part of which is a light grey calcite mudstone, with few fossils and poorly developed lenticular bedding. The lenses vary



TEXT-FIG 1.—Map of the Geology and Cave Systems of the Castleton area.

from a few feet to over a hundred feet in length, with dips of about 40° N. at the entrance to the gorge gradually decreasing towards the cave entrance, where a few widely spaced bedding planes appear. These are nearly horizontal in the entrance but when traced north or south run together. In one case they enclose a lens 200 feet long and 15 feet thick. The Swine Hole and Resurgence passages are formed in these bedding planes and show a dip of about 10° E. within the cavern swinging to nearly horizontal just outside (Text-fig. 2). A study of these bedding planes demonstrates that the reef is composed of a series of overlapping shoals.

The highest beds seen in the gorge gradually become more fossiliferous towards the crest of the reef and near the Castle shell beds with



TEXT-FIG. 2.—Plan (A) and Section (B) of Peak Cavern.

abundant reef brachiopods and *Beyrichoceras micronotum* (Phil.) and *B. castletonense* Bisat. are found.

The lowest beds in the vestibule consist of a rather dark crystalline limestone which overlies a somewhat brecciated bed with many small reef brachiopods, e.g. *Pugnax*, *Dielasma*, *Schizophoria*, and *Productus*, and also a cluster of *Caninia sp.* Both these beds can be traced through into the Great Cave with their initial gentle southerly dip decreasing there. High on the west side of the Great Cave in the entrance to the Orchestra Gallery, there is a sharp change from the dark crystalline limestone to the overlying light-grey calcite mudstone, and the contact can also be found, after some climbing, in Roger Rain's House, where a small fault containing the lead vein seen in Cavedale displaces the beds a few feet down to the south.

In the Great Cave and Roger Rain's House bedding is much better developed, but still shows a tendency to enclose lenses. This can be seen in the passage connecting the two chambers. From Roger

Rain's House to the top of the Devil's Staircase the cave roof follows a single bedding plane and then cuts steeply down into a lower one, which forms the roof of the rest of the cavern as far as the Victoria Cavern.

Until 1949 the farthest point in the cavern was just beyond Victoria Cavern at an altitude of 640 feet O.D. approximately under the outcrop of the lava in Cavedale. Diving operations disclosed more than a mile of caverns beyond this point and the same bedding plane can be followed almost over the entire distance. Erosion has exposed about ten feet of the bed above and up to forty feet of the bed below. The dark limestone gradually becomes lighter and scattered crinoids appear in this part of the cave. Its lithology is closely comparable with that of the S_2 limestones exposed near Peak Forest, where the sharp change from dark limestone to light grey calcite mudstone is taken as the base of D_1. The whole of the inner series of caverns shows a regular dip of about 4° E.S.E.

It is suggested, then, that whilst the inner parts of the cave are in massif facies S_2 limestones, the outer parts and the gorge are in reef facies, and there is no break between the two. Two small lead veins crossing the gorge show minor displacement but the major joint crossing the Great Cave shows none. The sub-reef unconformity postulated by Shirley and Horsfield (1940) if projected downward from the position shown on their map should cross the cavern section between the entrance to the gorge and the Devil's Staircase, but there is no evidence of its presence here or in any other part of the section. If the highly fossiliferous beds near the castle are to be regarded merely as a skin on the denuded massif limestones, as the above authors have suggested, then it is highly significant that beds with reef brachiopods occur in Peak Cavern over 300 feet vertically below them.

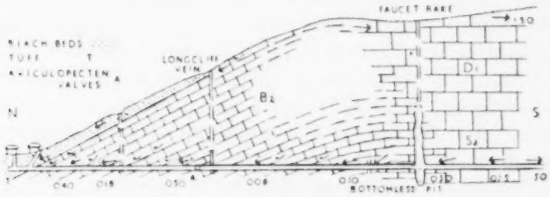
Speedwell Mine

The Speedwell Mine and Caverns give the most complete traverse of the Carboniferous Limestone from the beach beds through the reef limestones into bedded S_2 limestones. Immediately north of the road at the foot of the Winnats Pass a shaft was sunk for 72 feet, commencing near the top of the beach beds which outcrop nearby. From the bottom of this shaft a level roughly 7 feet high and wide was driven almost due south for some 600 yards at 742 feet O.D. (Text-fig. 3). It then turned south-west and later west for a further 400 yards, and intersected an east-west drainage system in this latter stretch. At a point 500 yards from the shaft a very high but narrow cavity in a mineral vein was broken into at about 90 feet above the floor. The first section of the level and this cavity, now known as the Bottomless Pit Cavern are open to the public, and constitute the more

important part of the section, although its examination is difficult owing to permanent flooding to a depth of 3 ft. 6 in.

The beach beds with their characteristic worn and broken Productus valves are seen in the shaft, in the more recent staircase (immediately south of the road) and in the first few yards of the level. They show well-developed bedding with a dip 25° N.E., and a bed of clay up to 3 inches thick with pebbles of limestone embedded in it marks the base of the group. The pebbles are similar to those in the Cavedale tuff (Parkinson, 1947). The next few yards reveal three other thin clays with lenses of breccia and reef limestone between, and there is some evidence suggesting repetition of the clay by slipping.

The remainder of the level is in typical fine grey reef limestone, traversed by a number of thin mineral veins. Bedding is obscure,



TEXT-FIG. 3.—Section of the first part of the Speedwell Mine.

and the limited number of dips obtained show a general N.N.E. direction varying in amount from 5° to 35°. The highest value is close to a thin mineral vein, and may be due to faulting. Longcliff Vein shows a small displacement at the surface, but none was detected underground. Reef brachiopods such as *Martinia*, *Dielasma*, *Pugnax*, *Schizophoria*, and various productids and spirifers can be seen in the walls, as well as local accumulations of *Aviculopecten* valves and other lamellibranchs, including *Posidonia vetusta*, but no corals or goniatites were observed. Towards the Bottomless Pit brachiopods other than productids become less common and crinoid debris dominates. Both walls of the Bottomless Pit Cavern consist of a fine light grey crystalline limestone with crinoids, indistinguishable from S_2 limestones of Peak Forest. Their dip was still N.N.E. but gentle.

Beyond the Bottomless Pit the remainder of the level and the natural watercourses are in the same limestone with the dip decreasing and swinging to the east. About a hundred yards south of the Bottomless Pit a natural watercourse has developed in a bedding plane dipping 10° E.N.E. At the end of the artificial level a large natural cave passage containing a stream draining eastwards to the Russet Well can be followed for half a mile in either direction, and tributary passages extend north-west for similar distances. The whole of these

passages have developed in a bed of clay about 2 inches thick. Erosion has cut into the limestone bed above up to 4 feet, and into the underlying bed up to 30 feet. The latter contains scattered colonies of *Lithostrotion* and *Syringopora*. The dip is east in the main passage, and swings to E.S.E. in the tributaries.

The whole system except for the first 300 yards is thus below bedded D_1 limestone at depths of approximately 600 feet, and so is well down into the S_2 zone. The first 300 yards are below the steeply dipping reef limestones and beach beds as mapped by Shirley and Horsfield on the surface. Over this distance no evidence of cliffs, boulders, beds, or any break in the limestones other than that occasioned by mineral veins can be found; and the outward marginal component of dip extends further south than on the surface.

It may be noted here that the officers of the Geological Survey (Green, 1887) erroneously placed the Bottomless Pit Cavern in New Rake and the watercourses near Dirtlow Rake. This misapprehension may have followed from their acceptance of the fact that the first section of the level is locally reputed to be 750 yards long, whereas it is just short of 500 yards. The Bottomless Pit Cavern thus occurs in Faucet (or Foreside) Rake, about 100 yards west of Longcliff Plantation and the watercourses lie in and immediately north of New Rake. The latter is plainly visible in several places as about four feet of calcite with very little galena although attempts to work it have been made, mainly in the late eighteenth century.

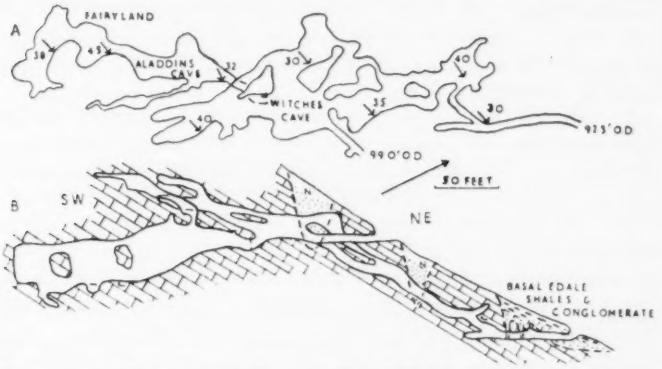
Treak Cliff Cavern

The section in Treak Cliff Cavern is considerably shorter and less complete than the foregoing, but is no less interesting, lying as it does almost entirely within the reef limestones of Treak Cliff. The entrance is on the east face of Treak Cliff at 925 ft. O.D. and the cavern extends roughly south-west for about 150 yards rising to just over 1,000 ft. O.D. in the middle and descending to 950 ft. O.D. at the inner end. The first half of the cavern is thus parallel to the surface slope and nowhere more than about 40 feet deep (Text-fig. 4).

The entrance is in an outlier of Edale Shales about 30 feet thick which rest in a hollow in the limestone and which have a dip parallel to the limestone surface, probably due to compaction. These shales are now only visible a few yards along the entrance tunnel but were temporarily exposed at the surface two years ago. The basal layers contain large rounded and corroded boulders of crinoidal limestone generally 6 inches to 2 feet in diameter, not often in contact with one another. These may be considered as a basal Namurian conglomerate, although the exact age is unknown as the only fossils obtained so far are conodonts. " Neptunean Dykes " of similar black shale, somewhat

crushed, occur a few yards further along the tunnel and also yielded conodonts. Similar " dykes " also occur near the upper entrance.

The limestones below the conglomerate are rather dark and coarsely crinoidal and resemble the beds seen below the shales in the car park at the foot of Treak Cliff. These limestones, which extend throughout the cavern, show an easterly dip from 30° to 45° and crinoid stems and broken Productus valves are commonly seen forming layers with this steep dip. *Posidonia becheri*, broken *Aviculopecten* valves and a goniatite, probably of the *Goniatites maximus* group, were found in " Fairyland ", whilst crinoid cups are visible in the entrance to " Aladdin's Cave ". In the roof of the " Witches Cave " near the



TEXT-FIG. 4.—Plan (A) and Section (B) of Treak Cliff Cavern, showing " Neptunean Dykes " (N).

upper entrance tunnel, are " Neptunean dykes " of a different type from those described above. They take the form of large fissures in the limestone filled with angular and subangular boulders of limestone in a matrix of shaly and bituminous limestone, and are thus closely similar to the well-known " dykes " at Windy Knoll. The " dykes " in Treak Cliff Cavern are interpreted as grikes in the Pre-Namurian land surface filled in with littoral deposits during the advance of the Namurian sea.

Two types of " dyke " are thus seen to occur in reef limestone of B_1 age in Treak Cliff Cavern ; one filled with shale and the other with breccia. The same phenomena were described by Shirley and Horsfield (1940) at Windy Knoll, where the latter type occurs in limestones with *Paleosmilia murchisoni* and *Davidsonina septosa* (D_1 index fossils) and is filled with boulders containing the same fossils. These authors regarded such an occurrence as evidence of the sub-reef unconformity (i.e. pre-B_2), and the breccia infilled " dykes " were considered to be of a different age from the shale-filled " dykes " which occurred a few yards away. Both types of " dyke " are here recorded within the same

beds of reef limestone at Treak Cliff Cavern and it is now established that closely similar " dykes " occur in both reef and massif facies. Proof that these two types of " dyke " are of different age is lacking, and the evidence suggests a similarity of age.

Treak Cliff Cavern, with its steeply dipping reef limestones throughout, extends at its inner end (altitude 950 ft. O.D.) close to one of the " sea-stacks " of D_1 massif facies limestone believed by Shirley and Horsfield (1940) to project through the Castleton Reef Limestones near the south end of Treak Cliff at an altitude of 1,310 ft. O.D. Their evidence for this " stack " was based on their discovery of *Davidsonina septosa* in isolated crags on the summit of Treak Cliff. From the present evidence such a " stack ", if it had existed would have been at least 350 feet high and possessed nearly vertical sides. It is difficult to believe that this could have stayed in position during submergence and burial by " submarine screes ".

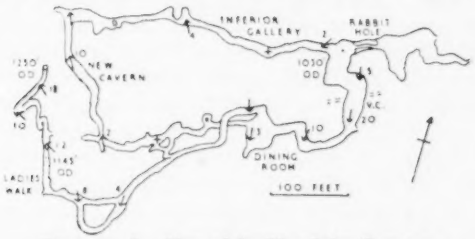
It may be mentioned here that the first part of the cavern is heavily mineralized, the chief mineral being the Blue John variety of fluorspar. The deposits are in joints, along bedding and in small solution cavities and also as replacements of the walls of these. The deposits are confined to the uppermost beds of limestone, i.e. those originally nearest to the Namurian shale cover, suggesting that the mineralizing solutions rose up the dip slope of the reef limestones from the direction of the basin, spreading out immediately below the shale cover in what the Derbyshire miner calls a " pipe-vein ".

Blue John Caverns

These caverns, occurring entirely within the massif facies limestones as mapped by Shirley and Horsfield (1940) were not expected to yield information concerning their problematical relationship with the reef limestones. However the greater part of the ramifying passages and working were examined, a smaller portion being unsafe owing to rotting timber. The whole system has been formed in gently dipping bedded limestone (Text-fig. 5).

From the entrance (1,250 ft. O.D.) to the Ladies Walk (1,145 ft. O.D.) a thickness of about 100 feet of coarse crinoidal limestone is penetrated, with a lithology which resembles the crinoidal reef limestone of Treak Cliff Cavern. The basal 12 feet of these beds contain abundant chert nodules, visible in the roof and walls of the Ladies Walk. Immediately below is a thin clay parting which in turn overlies a group of massive finely crinoidal limestones at least 150 feet thick, rather dark at the top but lighter lower down. Fine crinoid debris occurs in bands a few inches apart throughout these limestones although the bands become more irregular and sometimes even lenticular in and beyond the Variegated Cavern (V.C. of Text-fig. 5). The presence of rapid current

action and sorting is suggested by the debris and by the scattered colonies of *Syringopora* some of which are overturned. Occasional colonies of *Lithostrotion* are present in these limestones which are also visible in the Inferior Gallery and in the New Cavern. The limestone exhibits a gentle dip throughout and reaches a maximum in the Variegated Cavern at 20°. A small anticlinal structure occurs with its axis approximately bisecting the angle between the two main galleries. An east-west fault crosses the Variegated Cavern, and its breccia, about four feet wide, might be mistaken for boulder beds owing to mineralization obscuring detailed structure, but there is no appreciable change in dip or in lithology on opposite sides. The breccia has not been detected elsewhere in the cavern but a master joint along the same strike occurs



TEXT-FIG. 5.—Plan of the Blue John Caverns.

just north of Lord Mulgrave's Dining Room. Scattered reef brachiopods and reef tufa occur near the Rabbit Hole (1,030 ft. O.D.).

The Blue John Caverns give limited lithological evidence of facies change from massif to reef limestones, but the steep dip of the reefs is nowhere seen, although on the surface they are only a short distance away. Evidence of rapid currents has already been given and it seems that the transition between facies was rapid at this most northerly point of the Derbyshire Massif.

GENERAL

There are several other caverns, not open to the general public, in the neighbourhood of Castleton but they shed little light on the massif-reef correlation problem. Oxlow Caverns and Nettle Pot (see map) are both about 500 feet deep but with limited lateral extent and are entirely within massif facies limestones. Their only interesting feature is that the Cavedale Lava is apparently represented in a very attenuated form —as two clay beds with amygdules 18 inches and 6 inches thick and 20 feet apart in Nettle Pot, and as one clay 4 inches thick in Oxlow Caverns.

Giants Hole, lying one-third of a mile south-west of Windy Knoll, is of limited extent, and is complicated by minor faulting. However, some of the passages show an apparent continuation of the southerly

dip on the south side of Peakshill, a knoll with quaquaversal dips north of Giants Hole (compare Fig. 3–2c in Shirley and Horsfield, 1948).

Summary and Conclusions

The Castleton Caves present several continuous sections of the marginal reef limestones. Some of them continue from the reef into the massif limestones to the south. Although these sections are restricted in their width and height generally, they are unbroken in their length. No distinctive break or marked change in lithology between the two facies can be found, neither is there any sign of a break in the succession. At no place examined is there evidence of any boulder beds lying against cliffs at the base of the reef limestone. The evidence, on the other hand, strongly indicates a gradual transition between the facies, both in succession and in lithology, which is supported by the gradual loss of bedding characteristics on passing into the reef limestone. Structurally it is shown that the steep outward dips of the reef facies gradually decrease and may even be reversed within the cave sections. The decreasing dips pass gradually into the gentle easterly dip which characterizes the regularly bedded massif facies limestones. This evidence strengthens the suggestion made by Parkinson (1943 and 1947) and it may be concluded with him that the Castleton Reef Limestones are the lateral equivalent of the bedded limestones of the Derbyshire massif.

Acknowledgments

I would like to acknowledge the co-operation of members of the Sheffield University Mountaineering Club and of the Cave Diving Group in underground topographic surveying, often in extremely wet conditions. I would also like to thank the owners of the caverns, in particular Mr. H. Harrison of Treak Cliff Cavern, for permission to carry out this research on their property, and Professor L. R. Moore for reading the manuscript.

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Fossil Lineages and Environmental Change

By Kenneth A. Joysey

Abstract

An attempt is made to correlate the concept of the fossil lineage with our knowledge of polytypic species. The influence of changing environmental conditions in the geological succession and the relationship between geographical and chronological sub-species is analysed on a theoretical basis. The fossil lineage is considered to be the resultant of combined evolutionary and environmental change. Phenotypic modifications in response to environmental conditions are discussed in relation to the study of variation in fossil communities.

Introduction

IT is generally accepted that living animal communities are related to their fossil ancestors through a continuous series of intermediate morphological types. The existence of such a character gradient in time (chronocline), is the basic concept of evolutionary theory.

Study of the fauna of the present day time plane has revealed that some species are polytypic, being composed of intergrading geographical sub-species which in many cases form a cline in space (topocline). For example, the asteroid *Solaster papposus* has ten arms in the Arctic Ocean, eleven to thirteen arms in the waters around Greenland, Norway, and Britain, and fourteen arms in the Kattegat (Doederlein, 1902). Local variability of the marine gastropod *Littorina obtusa* has been demonstrated by a biometrical study of communities from Norway, Britain, and New England (Colman, 1932). The existence of geographical sub-species in some marine invertebrates is well established and it is important to recognize this factor in the consideration of fossil series.

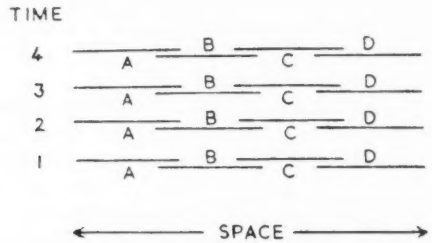
The present discussion is an attempt to knit together our knowledge of polytypic species and the concept of fossil lineages, and so emphasize the essential similarity of the topocline and chronocline.

Environmental Change

In attempting to correlate the concepts of chronological and geographical sub-species it is necessary to simplify the conditions. For example, it is possible to consider the theoretical case in which evolution is eliminated by the temporary arrest of all genetical changes. We may then consider a polytypic species on a single time plane, subdivided into four sub-species, A, B, C, and D, which overlap in their range of variation and geographical distribution (Text-fig. 1, Time 1). These sub-species are, in fact, arbitrary subdivisions of a continuous morphological series.

Then, considering a geological succession in which fossils are found at four horizons, if there has been neither evolutionary nor environmental change, the same sub-species will be found at any one locality (Text-fig. 1, Time 1–4).

If, however, there has been an environmental change which has led to changes in the geographical distribution of sub-species, then different sub-species will be found, even though there has been no evolutionary change (Text-fig. 2). At any one locality, the geological succession will now provide a series of chronological sub-species,



TEXT-FIG. 1.—A theoretical condition in which both Evolutionary and Environmental changes are absent.

which, in the absence of evolutionary change are identical with the geographical sub-species. This series would be indistinguishable from a lineage produced by evolutionary change.

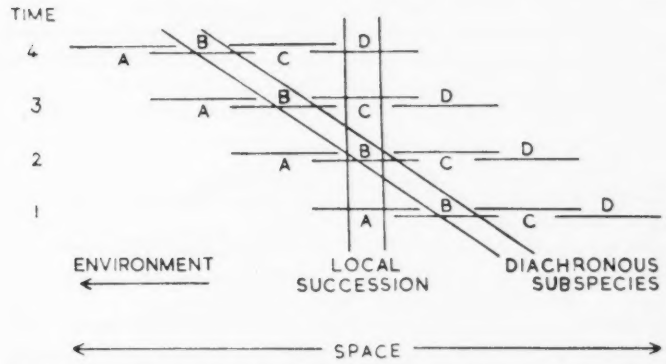
It is not probable that these theoretical conditions occur in nature, as true evolutionary (genetical) change is an additional complication. When considering a fossil "evolutionary" series there can be little doubt that both environmental and genetical changes have participated, and that the true interpretation lies in a combination of both factors, though their relative importance is debatable. However, even if a part of the change in a fossil "lineage" is due to the changing distribution of sub-species, then there will be *an apparent increase or decrease in the rate of evolution* of the series.

In the theoretical case of a non-evolving stock in a changing environment, it is evident that the sub-species are diachronous (Text-fig. 2) and hence their use for stratigraphical correlation would lead to erroneous conclusions. In fact, if the rate of change in the distribution is great then the sub-species will be distributed over a wide geographical range in a short interval of time, and it will, therefore, be the most useful type of fossil as a basis for time correlation. However, if there is only a small distributional change in a long period of time, then the sub-species will be more diachronous.

Phenotypic Modifications

There is still a further factor to be considered when discussing the effects of environmental change on animal communities. Morphological changes in an individual may be produced either by an internal change in the hereditary mechanism (genotypic change), or by the effect of external environmental conditions (phenotypic modification). Morphological changes throughout a community, in response to a changing environment, may be due to direct phenotypic modification, or to selection in favour of some particular genotype which previously had no opportunity of spreading, or to a combination of both.

Dall (1898) gave an account of the phenotypic variation in *Ostraea virginica*. He found that specimens in quiet water tended to be round



Text-fig. 2.—The effect of Environmental change in the absence of Evolutionary change.

and broad, whereas those in a strong current were narrow, elongate, and straight. In crowded conditions the elongate shells became irregular and laterally compressed. Oysters growing flat on the sea-bottom tended to be less strongly ribbed than those attached to a pebble, while those growing on a twig would tend to spread laterally near the hinge and curve to bring the distal margin uppermost. Specimens which were moved from one set of conditions to another altered their mode of growth.

A community of the fresh water gastropod *Limnaea peregra* from Leeds showed changes in the height of the spire and the size of the aperture when brought into standard culture conditions, whereas a community of the same species from Ireland retained its own peculiarities, which proved to have a genetic basis (Boycott, 1938 ; Diver, 1939). Without experiment is is impossible to distinguish whether the

characters of local races are phenotypical or are genetically fixed, and such experiment is impracticable for fossil communities.

Marine invertebrates may show phenotypical response to such factors as temperature, salinity, and the concentration of oxygen and trace elements. Availability of food may depend on the depth of light penetration which is influenced by climatic conditions and the quantity of sediment in suspension. These conditions may vary from season to season, year to year, or even in cycles of several years' duration. Individuals which lived under quite different conditions may be mixed together in the fossil accumulation on the sea floor. This fossil accumulation will show *a greater range of variation* than existed in the living community at any one time. The magnitude of this effect will depend on the relationship between rate of sedimentation and the periodicity of the environmental change.

An essential key to the interpretation of fossil communities lies in the study of living animals on the present day time-plane. Equally, the processes of evolution can only be seen in perspective when the zoological picture is projected along the dimension of geological time.

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A glacial erratic boulder of Shap Granite in South Northumberland

By G. A. L. Johnson

Abstract

The discovery of a glacial erratic boulder of Shap Granite in South Northumberland is recorded. Erratics of this rock have not previously been reported north of the Penrith area. It is suggested that the boulder was carried into Northumberland by ice flowing eastwards over the Tyne Gap.

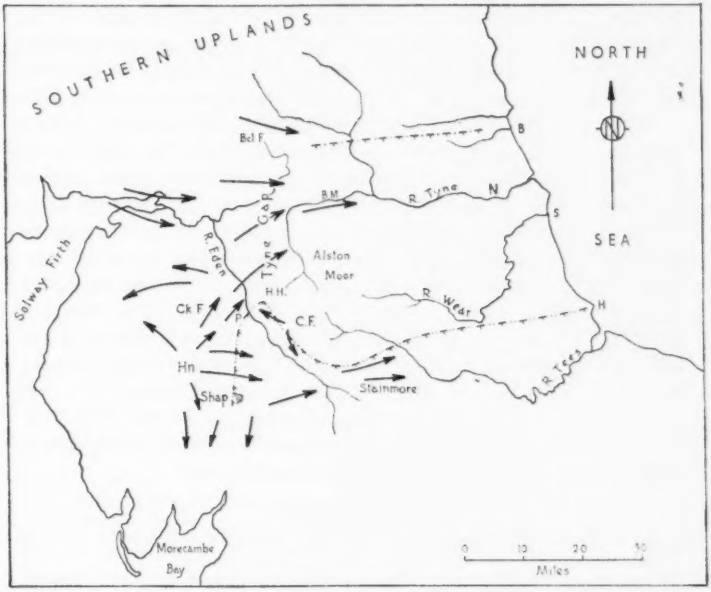
During a resurvey of the Carboniferous Yoredale succession of S.W. Northumberland, a single erratic boulder of Shap Granite has been found on high ground on the north side of the South Tyne Valley. The boulder is just under one mile N.N.W. of the Twice Brewed Inn near Bardon Mill, Northumberland; National Grid reference 35/744682. The erratic lies in a small peaty hollow at a height of *c.* 915 feet below the north-facing scarp formed by the outcrop of the Great Whin Sill. The scarp reaches a height of 1,230 feet O.D. in the immediate neighbourhood and forms a prominent, though discontinuous, ridge between the position of the boulder and the South Tyne Valley. The erratic is roughly rectangular in plan, being three feet long by nearly three feet broad, and at one end over two feet of the boulder are visible above the ground surface. The shape is generally well rounded though the surface is rough and uneven, due to the coarse porphyritic texture of the rock. The erratic is composed of the characteristic red Shap Granite containing abundant large feldspar phenocrysts.

The remarkable dispersal of Shap Granite from the outcrop at Wasdale Crag, on the west side of the Vale of Eden, was probably first described by Professor Phillips in 1837. Since that time the dispersal has been studied by several workers and is now a well-known example of the scatter of an indicator erratic. In the Vale of Eden, Shap boulders are concentrated to the east and south of the granite outcrop; a few erratics are found to the north, but these decrease in number rapidly when traced down the valley. The main direction in which the erratics were carried is shown by two trains of boulders, one of which leads over the Pennines through the pass of Stainmore into Teesdale and ultimately to East Yorkshire; the other is traceable southwards to Morecambe Bay and into the Midland counties. North of the granite outcrop the occurrence of Shap boulders decreases towards a line through Penrith and Melmerby beyond which no boulders have previously been recorded (Hollingworth, 1931, p. 346). It appears that the dispersal of the boulders, both up and down the Eden Valley, is due to the complex nature of the Eden ice stream

during the Maximum (= Main) Glaciation of Northern England. Dr. Trotter (1929, p. 562 et seq.) has shown that, at this period, ice at the north end of the vale moved in a northerly direction, while at the head of the valley the ice movement was southwards towards Stainmore. The dispersal of Shap boulders down the Eden Valley was thus against the main ice movement; Hollingworth (1931, p. 347) has suggested that they were carried northwards by basal ice which moved in a direction opposite to the main ice stream. He notes the possibility that this northwards dispersal might not wholly have taken place at the maximum glaciation (ibid., p. 346), but remarks that this does not seriously affect the problem. This argument is also, perhaps, applicable to the new record of a Shap boulder in Northumberland, which initially must have been carried northwards down the Vale of Eden. On the east side of the Pennines, Shap boulders were carried by the Teesdale glacier into Durham and East Yorkshire. The most northerly record in Durham is stated by Trechmann (1915, p. 77) to be at Elwick, four miles west of Hartlepool. Towards the Pennines the boulders become more common; the most northerly occurrence, excluding the Elwick record, being at a locality one mile S.E. of Bishop Auckland. It is evident that previous to the discovery of the erratic in Northumberland no Shap Granite boulders had been found north of the latitude of Melmerby.

In south Northumberland, far travelled glacial erratics from the south of Scotland and the Lake District are found in fair abundance, and in the eastern part of the county the latter have a definite northern limit roughly along the divide between the rivers Blyth and Wansbeck (Smythe, 1912, p. 93). Erratic boulders from the Lake District have been traced as far north as Houxty Burn, two miles N.W. of Wark, in the valley of the North Tyne, by Dwerryhouse (1902, p. 597), and still further to the west, in the Tyne Gap area, these erratics are found over the wide stretch of country between Hartside Height in the south and the Bewcastle Fells in the north (Trotter, 1929, p. 561). With the exception of a small area around Cold Fell, which appears to have been an independent ice cap (ibid., p. 566), all the Tyne Gap area was completely overriden by ice flowing from the west. This ice stream, passing eastwards into south Northumberland, carried with it many Lake District erratics; a typical assemblage of these boulders has been recorded in the Bardon Mill district by the Boulders Committee (7th report, 1914, p. 225) as follows: " Volcanic series of Borrowdale; Granite (Skiddaw ?); Threlkeld Granite (microgranite); Gabbro (Carrock Fell ?)." This assemblage of Lake District erratics is quite characteristic of the glacial drifts of south Northumberland and has been recorded at several localities: as far east as Newcastle, by the Boulders Committee. Boulders of the Armboth Dyke rock have also

been recorded in the drifts of this area. It would appear that the ice which carried these boulders into Northumberland proceeded from the northern Lake District, for the outcrops, whence these various common erratics were derived, are all concentrated on the north side of the Helvellyn range. It is considered probable that the Shap Granite boulder found near Bardon Mill was finally carried into its



TEXT-FIG. 1.—Reference map.

T·T·T·T·T·T = Northern boundary of the Lake District erratics in Northumberland.

T''T''T''T''T''T = Previous northern boundary of Shap Granite dispersal. The arrows denote the general direction of ice movement at the Maximum.

B. = Blyth ; Bcl.F. = Bewcastle Fells ; B.M. = Bardon Mill ; C.F. = Cross Fell ; Ck.F. = Carrock Fell ; H. = Hartlepool ; H.H. = Hartside Height ; Hn. = Helvellyn ; N. = Newcastle ; P. = Penrith ; S. = Sunderland.

present position by the eastward flowing ice stream which passed over the Tyne Gap.

On the Pennine escarpment to the N.E. of Penrith, deposits of glacial drift containing erratic boulders from the Lake District have a southern limit near Hartside Height. It may thus be assumed that this locality is not far from the southern boundary of the main eastward flowing ice stream over the Tyne Gap. The most northerly record of

Shap Granite erratics in the Vale of Eden at Langwathby, four miles N.E. of Penrith (Harkness, 1870, p. 519) is in a position which is only seven miles S.W. of Hartside Height. Apparently any Shap Granite boulders that travelled far north of Langwathby would come under the influence of the eastward flowing ice stream and be carried over the Tyne Gap into south Northumberland. This could explain the occurrence of a Shap Granite erratic near Bardon Mill and also perhaps the position of the northerly limit of Shap boulders in the Vale of Eden at Langwathby. The position of the new record, high above the South Tyne Valley and beyond the bold scarp of the Whin Sill, is possibly evidence that it was carried to its present resting-place at or near the time of the Maximum Glaciation. The number of Shap Granite erratics which travelled down Edenside as far north as the Penrith area is relatively few, and only rare boulders can have reached the easterly flowing ice stream to be carried over into the Tyne Valley. There is a possibility, however, of individual boulders reaching the east coast of England by this circuitous route. This route has been previously suggested by Wright (1936, p. 69), who shows that Shap Granite boulders could be carried down the Vale of Eden, pass over the Tyne Gap into the Tyne Valley and thence travel eastwards to the coast. The discovery of the new Shap Granite record near Bardon Mill in Northumberland, lends support to this hypothesis.

In conclusion, I should like to extend my thanks to Professor T. S. Westoll and Dr. A. Raistrick, who have read the manuscript and whose suggestions and advice are gratefully acknowledged.

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On the Development of *Diversograptus* Manck

By Isles Strachan

Abstract

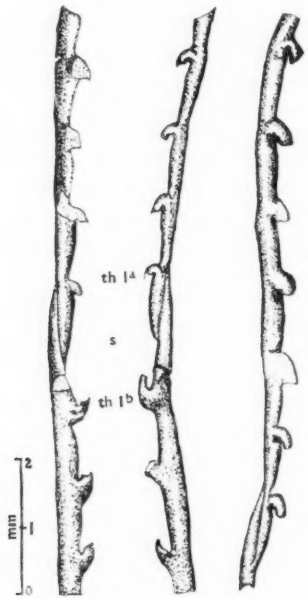
Specimens of *Diversograptus* are described which show conclusively how the two stipes arise from the sicula. This is also the first record of the genus occurring in Britain.

THE genus *Diversograptus* was erected in 1923 by Manck for those Silurian graptolites consisting of two uniserial stipes growing in opposite directions from a sicula. These stipes may be straight or variously curved and may themselves " branch ". The material studied by Manck was all rather poorly preserved (the graptolites being found as silvery films on the black shales) and he was unable to say how the two main stipes arose from the sicula. The lateral branches appeared to be cladia of the usual cyrtograptid type. Bouček, in his monograph on the Cyrtograptidae (Bouček, 1933), briefly redescribed the genus but did not contribute any further information on its structure. Bulman (1938) placed *Diversograptus* in the Monograptidae beside *Cyrtograptus* and suggested that one of the main stipes was possibly of the nature of a cladium from the sicula, the other being presumably a normal uniserial monograptid stipe.

Several references to the genus have been made since then in Swedish, Bohemian, and German literature (e.g. Hemmann, 1943), but no further details of structure have been given. The purpose of this note is to describe some British specimens which show clearly the mode of development of the stipes, which is as Bulman suggested.

During a re-examination of some graptolites in the Lapworth Collection in Birmingham University, the writer came across some specimens which clearly could only be referable to *Diversograptus*, a genus not hitherto recorded from Britain. Shortly after this, some more specimens were found which had been identified as *Diversograptus* sp. by B. Waern of Uppsala during his visit to Birmingham in 1948. None of these specimens, however, showed the sicula clearly. Finally two specimens turned up in which the sicular portion with its two stipes was well preserved. These specimens were both labelled as *Monograptus runcinatus* Lapw. in Lapworth's writing, and on looking up the original description of that species (Lapworth, 1876), it was found that Lapworth had figured " bilateral specimens " in both *M. runcinatus* and *M. becki*. These were, however, apparently regarded as only abnormal specimens and no mention of their occurrence was made in the *Monograph of British Graptolites* (Elles and Wood, 1901–18). Amongst the original German material described by Manck (which is now in Brussels and is being studied by the writer)

there are more than a hundred specimens of his species of *Diversograptus* and there seems to be no reason for not regarding the genus as valid. Further consideration of this point will be made later. No "bilateral" specimens of *M. becki* have come to light as yet and Lapworth's observations require confirmation before it can be decided whether this species is a *Diversograptus* also.



TEXT-FIG. 1.—*Diversograptus runcinatus* (Lapw), Glenkiln Burn, Dumfriesshire. All specimens in Lapworth Coll., Birmingham University. s = sicula. th 1^a = 1st theca of normal stipe. th 1^b = 1st theca of secondary stipe. Approx. 10 ×.

Both the British specimens figured here are in full relief, being originally probably pyritized but now altered to limonite with parts of the carbonaceous film representing the original skeleton still present. Unfortunately, it is not possible to make out any growth lines. In one specimen (Text-fig. 1*a*), the sicula has been broken away, leaving a cast, and this shows clearly that one of the main stipes has the normal monograptid development, with the initial bud appearing fairly low down on the sicula. When traced further downwards

the sicula appears to be constricted slightly before growing on and developing the hooked aperture characteristic of the later thecae. From the back of this hook the second stipe continues in the normal monograptid fashion when there is little overlap of the thecae. It should be noted that this first theca of the second stipe, $th1^b$, has an extremely short proximal portion apart from the sicula itself, which is quite different from the common appearance of a cladium in a cyrtograptid where there is always a longer proximal portion in the first than in the later thecae of a branch. This may imply a different mode of development of the main stipe here from that of a normal cladium, especially as in the branched German specimens the branches are typical cladia, but until further information on the organization of graptolites is available, these can be only matters of speculation. A virgula has been seen in both stipes of *Diversograptus* and the two main stipes appear to be identical in all except origin.

From the specimens available it is not possible to determine at what stage of growth in the rhabdosome the second stipe arises. Most of the associated fragments show no sicula but one specimen on the same slab as Text-fig. 1*b* appears to be the same form but without the second stipe (Text-fig. 1*c*). It is about 8 mm. long and by itself would undoubtedly be placed in the genus *Monograptus* but from the association it is more probably a *Diversograptus* in which the second stipe has not yet developed.

As mentioned already, there are many specimens of *Diversograptus* in the Manck Collection from several localities and varying horizons. There seems therefore to be little reason for rejecting the genus as merely an abnormal form of *Monograptus*. Like *Cyrtograptus*, *Diversograptus* species pass through a monograptid stage which may be sufficiently long for young specimens to be identified as *Monograptus* spp.

Most of the specimens of *Diversograptus* in the Lapworth Collection are labelled as *Monograptus runcinatus* Lapw. and are from the Upper Birkhill shales, Glenkiln Burn, Dumfriesshire. They include one of the specimens figured in Elles and Wood (plate xlv, fig. 2*d*) in which the specimen is continued as a cast with an obscure sicula and two thecae growing in the opposite direction to those figured. The same slab, however, bears a better specimen showing the sicula and two stipes clearly. It seems probable that *M. runcinatus* is really a *Diversograptus* and is distinguished from those described previously by its characteristic thecal form. The varying thecal form seen in the drawings is due to some parts of the specimen being broken away leaving either casts or flat broken surfaces. It may be noted that in no case has any interthecal septum been seen in the broken thecae although traces of the outer thecal walls are clearly seen.

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So-called Amygdaloidal Gabbro, Skye

By E. B. Bailey

Abstract

Certain amygdaloidal rocks in Skye have formerly been interpreted as lavas in which the matrix of the amygdales has been replaced by, or alternatively metamorphosed into, material such as one expects in intrusions. It is now claimed that the amygdales formed in intrusions in normal fashion.

In a recent paper Doris L. Reynolds (1951, p. 87) records how, on the prompting of H. G. Backlund, she obtained " the clue to the understanding of the structure of Slieve Gullion ", a Tertiary igneous centre 55 miles N. of Dublin. It came to her through reading " with new attention and inquisitiveness " Harker's interpretation of certain amygdaloidal rocks in the Cuillins of Skye (Harker, 1904, p. 95). To make the matter definite I quote three paragraphs from her acknowledgment :—

" The gabbro of the Cuillins, according to Harker's description, thus consists of many sills, of varied petrographic types, which are intruded, sometimes transgressively, into a volcanic pile of basaltic lavas and agglomerates. Having established these primary relationships, Harker goes on to record that ' There are places where the relation between the basaltic lavas and the gabbro are of a more remarkable character. . . . This is found at numerous localities on the western and south-western slopes of the Cuillins. . . . The eye is caught at once by conspicuous amygdules, comparable with those seen in the metamorphosed lavas, but here occurring in what has otherwise the appearance of a normal gabbro . . . Thin slices confirm the statement that the enclosing rock has the character of an ordinary gabbro. They also make it certain that the amygdules are enclosed foreign bodies, not patches of secondary minerals occupying druses in the gabbro '. Occasionally, indeed, the amygdales are surrounded by ' a relatively fine-textured rock, which must be regarded as a metamorphosed basalt.' Furthermore, ' the amygdaloidal gabbros occur . . . always in the immediate neighbourhood of the metamorphosed lavas.'

" Harker considered that ' Two alternative explanations are not inconsistent with the facts as so far stated. We might suppose that the amygdaloidal gabbro represents the extreme phase of metamorphism of amygdaloidal basalt, all the original character of the rock except the amygdules having been obliterated or, on the other hand, that the basalt has actually passed into a state of fusion and mingled with the gabbro magma, only the amygdules surviving '. Harker rules out the former hypothesis on the grounds (1) that the gabbro presents features (e.g. schiller structures in the augite) ' which are highly distinctive

of true plutonic rocks, and are not be expected in any product of thermal metamorphism', and (2) that similar amygdales are locally present in the ultrabasic rocks and present the same indications of a foreign origin.

" With regard to (2), Harker remarks that ' Since no metamorphism could convert a basaltic lava into a picrite or peridotite, it is clear that in that case at least the lava, with the exception of its amygdules, must have been fused, and must have become sufficiently fluid to diffuse through the ultrabasic magma, mingling freely with it '. In the light of modern knowledge," Reynolds continues, " this conclusion of Harker's is unsound, for it is quite conceivable that basaltic lavas or rocks derived from them by weathering (including laterite and bauxite) could be converted to ultrabasic rocks by basic front action. On the other hand, if an ultrabasic or gabbro magma can be supposed to have fused a mass of solid basalt, it is quite impossible that the amygdales of the basalt could remain unfused, and become dispersed throughout the invading magma. Harker, moreover, casts doubts on his own conclusion, and provides evidence for the metamorphic origin of the amygdaloidal gabbro, when he confesses that ' in actual mapping it is not always easy to divide sharply the amygdule-bearing gabbro from a highly-metamorphosed amygdaloidal basalt '. One can only conclude that Harker's observations carry the implication that basalts in Skye have been locally transformed to gabbro and peridotite."

Harker's statement of evidence is so explicit that it might well be accepted without question, if only it led to some commonplace conclusion ; but such is not the case. As we have just seen, two alternative explanations have been offered. Harker, confident as a result of his examination that particular amygdales originated in lavas and that their matrix does not have the character of lavas, but of intrusions, claims that the amygdales must have persisted despite the remelting and partial displacement of their pristine matrix. Reynolds, on the other hand, while accepting without hesitation Harker's diagnosis as to the origin of the amygdales and as to the incompatibility between them and their matrix dismisses his remelt solution of the puzzle as " quite impossible ". Instead she advocates metamorphism of the matrix, developing basalt into gabbro. At first sight Reynold's position seems the more reasonable, but we have been forewarned by Harker that the matrix " presents features . . . which are highly distinctive of true plutonic rocks, and are not to be expected in any product of thermal metamorphism ". Accordingly it seems advisable to reconsider carefully the foundations upon which such daring hypotheses, involving either remelt or an unusual type of metamorphism, have been erected.

I have been kindly permitted by the Geological Survey to consult

their collection of sliced rocks. Harker has labelled four slices in this collection (S. 8698–8701) as "Gabbro enclosing amygdules", and has alluded specifically to the last three of them in his text, part of which is quoted above. The results of my re-examination may be summarized as follows. All four specimens are of a texture, which, in combination with their composition, justifies Harker's claim that they are normal intrusive igneous rocks. Three out of the four show indications of contact-metamorphism, but only to a very minor extent. At the same time not one of the specimens is a gabbro in the ordinary sense of the term. Three (S. 8698–8700) are what I call tholeiitic dolerite; and these carry unquestionable amygdales such as one expects from experience to find in tholeiites. The fourth (S. 8701) is a rather coarser quartz-dolerite, with irregular patches of quartzo-felspathic material presumably filling what had temporarily been miarolitic or drusy cavities. Similar patches are often found in quartz-dolerites and quartz-gabbros, but it is not customary to call them amygdales.

I realize that present-day readers may be puzzled by differences of terminology, as well as of interpretation, distinguishing this account from that given by Harker. The difficulty arises largely from the fact that Harker was apt to allow a useful generalization to develop in his systematic treatment into something approaching an inflexible rule. Let us consider the generalization that basic sills are often coarser than basic lavas. This led Harker in many cases to speak of basic sills as dolerite irrespective of texture. For instance, once he had satisfied himself (I am quite sure mistakenly) that the fine-grained columnar basalts of Staffa and the Giant's Causeway are sills, he started to class them as dolerites. I presume that Harker in like manner used the name gabbro in relation to the amygdaloidal rocks under discussion, because he recognized them, on account of their texture, as manifest intrusions, and, on account of their location, as part of the great Cuillin complex of gabbro.

Similarly we know that Harker was frequently misled by the generalization that lavas tend to be much more amygdaloidal than intrusions. Thus, as has been indicated on previous occasions, he divided many an individual Hebridean flow into amygdaloidal basalt lava above and massive dolerite sill below—this accounts for most of the sills of what he called his Great Group in Skye. To recognize individual amygdales in the Cuillins as derivatives of lava enclosed in a matrix of intrusion was but an exaggeration of the same tendency.

Harker did of course realize that there are such things as amygdales in sills and dykes, and the reader will find a few useful notes on the subject indexed in the Skye memoir. In fact, we shall have occasion shortly to refer to an example which he has specially illustrated.

Before, however, we turn to this and other comparable material, here are a few words about Harker's four Cuillin slices labelled " Gabbro enclosing Amygdules ".

(S. 8698) is a tholeiitic dolerite, in which many of the feldspar laths are about 1 mm. long. There is plenty of fresh ophitic augite. There are also two irregular patches of acid mesostasis, and a score of chlorite-filled amygdules, one of which has a diameter of 5 mm. The whole is a typical unmetamorphosed igneous rock. Its feldspars (in common with those of the other three slices) are not very fresh, but their condition is such as is commonly found in tholeiites and quartz-dolerites that may have suffered auto-pneumatolysis. To me there seems no doubt that its amygdales are a normal feature of the containing rock.

(S. 8699) is a tholeiitic dolerite, in which, as so often in similar rocks elsewhere, there is considerable variety of crystallization. Some scattered feldspars measure up to 5 mm. by 2 mm., but most of the laths are about 1 mm. long. The detail of the matrix between the laths is obscure owing to decomposition ; but there has been much ophitic augite, replaced apparently in large measure by dirty fibrous hornblende—almost certainly a product of slight contact-alteration. In an irregular tract, which, reaching across the slice, contains but few of the bigger feldspars, there are five round amygdales, the largest measuring 4 mm. across. They are outlined by tangential, and sometimes radial, feldspars ; and usually have quartz in the centre. A couple show invasion by residual magma, which has crystallized in the fashion so often noted in tholeiitic amygdales. There are also a few smaller chlorite-filled amygdales, and these on occasion interrupt the form of the bigger feldspars. In addition there are inconspicuous intersertal patches of late-crystallized residual magma. Harker realized that the amygdales with tangential feldspars formed in the immediate matrix in which they are still enveloped. His comment is : " Here we have enclosed in the gabbro a small relic of basaltic lava, which itself encloses an amygdule." I think this a mistaken description of a somewhat patchy amygdaloidal tholeiitic dolerite.

(S. 8700) is a tholeiitic dolerite with feldspar laths commonly measuring 1 mm. long. There is a fair amount of fresh ophitic augite. Among a few amygdales, the most prominent measures 5 mm. across, and is largely filled with quartz. Marginal magmatic inwelling has led to crystallization of both feldspar and augite within a vague ring of tangential feldspar, which marks the outline of the original vesicle. Harker has pointed out that the interior quartz has recrystallized during contact-metamorphism, since it contains fibrous hornblende. He might also have cited contact biotite that serves as a discontinuous rim to another amygdale, mostly filled with fibrous hornblende.

Actually the whole rock shows corresponding contact-alteration, especially clearly marked in clouding of feldspars and disseminated biotite. This is important. Harker's view is that the amygdales were baked by their matrix, while I submit that they were baked along with their matrix.

(S. 8701) is a medium to coarse quartz-dolerite with feldspar laths often 2 mm. long, and corresponding big ophitic patches of augite. The latter are marginally altered with separation of iron ore. There are also some pseudomorphs almost certainly after olivine. Two feldspathic or felsitic patches, the larger measuring 2 cm. long, contain roughly-central areas of quartz. They extend marginally among the main feldspars of the groundmass. I hesitate to follow Harker in calling these patches amygdales, especially as he expressly distinguishes between amygdales and druses. At any rate I regard them as comparable with similar quartzo-felspathic patches commonly found in quartz-dolerites and gabbros. They do not, however, exhibit micropegmatitic growths such as are highly characteristic of " acid segregations " in Scottish Permo-Carboniferous quartz-dolerites. I regard this as an original difference, and not imposed by contact-alteration. At the same time Harker is right in pointing out that the quartzes of these patches have been subjected to contact-alteration as evidenced by development of fibrous hornblende and epidote. Again we note that the matrix of the patches shows comparable contact-metamorphism with local development of both hornblende and epidote.

While I recognize contact-alteration in three of Harker's specimens, I think that he has greatly exaggerated the position when he speaks of amygdales consisting " of an aggregate of felspar precisely like that described in the metamorphosed amygdaloidal " basalt lavas. Comparison with other material leads me to the view that most of the feldspar seen inside the amygdales is magmatic feldspar, not, as Harker suggests, " representing metamorphosed zeolites."

Analogies

In the Mull memoir it is pointed out that some of the ring-dykes of the island are composed of quartz-dolerite of what for local convenience is called Sgulan type (Bailey, 1924, p. 318). Among other features they show a " tendency to possess drusy or vesicular cavities that are usually invaded, at any rate marginally, by mesostatic material. This invasion of vesicular cavities by mesostasis has been recognized as a common characteristic of quartz-dolerites and tholeiites ever since Sir Jethro Teall (1889) drew attention to it in connection with the Tynemouth dyke of the North of England. The vesicles and druses alluded to above are frequently filled with quartz or chlorite in their more central positions (S. 17449, 17921) ". The two slices just quoted,

along with a companion (S. 17925) in which abundant fibrous hornblende has been developed, reproduce sufficiently closely most of the phenomena detailed in relation to the Cuillin material—though not the tangential feldspars of (S. 8699). It is noteworthy that the Sgulan type slices, which I have re-examined, agree with the Skye slices in not showing micropegmatite.

Tangential outlining of amygdales in intrusions is of course a very familiar phenomenon. Good illustrations have been given by Teall (1889), Harker (1904, pl. xxvii, fig. 2), and Flett (1910, pl. ix, fig. 6). It may or may not be associated with invasion of residual magma. Similarly, magmatic invasion of a vesicle may occur unassociated with tangential outlining (Falconer, 1906, pl. iii, fig. 3).

The examples quoted in the last paragraph are taken from typical tholeiites, definitely of finer texture than the Cuillin tholeiitic dolerites. The one illustrated by Harker is from a Skye dyke, corresponding in character " with the tholeiite of Rosenbusch ". The feldspars of the matrix (S. 5424) are generally about 1 mm. long.

I quote below some Geological Survey slices that illustrate amygdales in dykes and sills of the Scottish mainland, in positions where no one could suggest remelting or metamorphosis of matrix. The examples chosen are more or less comparable in composition with Harker's slices. Others, for instance among camptonites such as (S. 39136), might readily be added in cases where crystallization within vesicles has developed ocelli.

1. *Examples in which many of the feldspar laths of the matrix are* 1 *mm. long* :—

   S. 12616, 34246, 34274, 34285, 34304, 34319, 34356, and Ed. 1686.

2. *Examples in which many of the feldspar laths of the matrix are less than* 1 *mm. long* :—

   S. 11956, 11966, 12619, 34280, 34290–1, 34328–9, and Ed. 1677–9, 1692–3, 1872.

3. *Intermediate in texture between* (2) *and* (4) :—

   S. 11920, 13360, 14475, and Ed. 1694, 1705, 5426, 6187.

4. *Within* 8 *inches of the margin of a big sill* :—

   S. 14467–14474.

Those grouped under heading (1) are so nearly comparable with Harker's (S. 8698–8700) that I feel that they confirm conclusively my opinion that the latter represent normal amygdaloidal intrusions. Those grouped under headings (2) to (4) are progressively finer. Taking the twenty-two listed under (1) and (2) we find that fourteen of them illustrate invasion of vesicles by residual magma, fifteen show outlining of amygdales by tangential feldspars, while sixteen have chlorite, ten calcite, and ten quartz as amygdale minerals. Any combination of the

above features may occur. In the final category (4), confined to chilled edge material, magmatic invasion is scarcely traceable and tangential feldspars have not been noticed.

The list of comparative slices given above has been drawn up after going through material that happened to have been recently examined in the Edinburgh office of the Survey coupled with a big assortment of quartz-dolerites and tholeiites specially sent up from London as collected in the Linlithgow to Kilsyth district, Sheet 31. Even the coarse examples quoted are slightly finer in texture than Harker's (S. 8698–8700). I should call them tholeiites (or allied basalt) rather than tholeiitic dolerite. Where among the quartz-dolerites of Sheet 31 I found patches of feldspathic, quartzose, and chloritic material, I could only doubtfully ascribe them to amygdales in the ordinary sense. Similarly it will be noticed that the patches to which attention has been drawn above in the Sgulan type of quartz-dolerite in Mull have been ambiguously spoken of as occupying " drusy or vesicular cavities ". It seems that obvious amygdaloidal texture is commonly exchanged for drusy texture on passing from tholeiite to quartz-dolerite crystallization ; and that the Skye samples of amygdaloidal tholeiitic dolerite are of unusually coarse texture. At the same time I have no doubt that they owe their coarseness to original consolidation and not to subsequent change.

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So-called Amygdaloidal Gabbro, Skye : Comments on a paper by E. B. Bailey

By Doris L. Reynolds

Abstract

The suggestion that the Skye amygdaloidal gabbro represents amygdaloidal basaltic lava in which the grain-size has been coarsened by recrystallization does not imply " an unusual type of metamorphism " as Bailey supposes. Whereas recent lava-flows are fine-grained, older flows, particularly pre-historic examples, commonly have a doleritic or gabbroic grain-size. Bore-hole investigations in Yellowstone Park indicate that such increase in grain-size is a consequence of the long-continued through-passage of gases and water escaping to the surface. Bailey's own observation that amygdales within the Skye amygdaloidal gabbro " interrupt the form of the bigger feldspars " provides evidence that the bigger feldspars are younger than the amygdales, and that the rocks containing them have therefore recrystallized.

I AM indebted to Sir Edward Bailey for giving me a pre-view of his paper, and inviting me to supply some comments to appear in the same number of the *Geological Magazine*. After reading the paper several times I am still not sure what crime I am supposed to have committed. Since the evidence on which my interpretation of the Slieve Gullion rocks rests is entirely independent of that recorded by Harker from Skye, Bailey's implied criticism cannot be directed against my own work. It would therefore seem that I am supposed to have gone astray in accepting and quoting the evidence recorded by Harker. A year ago Bailey was complaining because he wrongly imagined that two young geologists had *not* recorded the relevant historical background. Now he is complaining that I *have* recorded the historical background. Far from being penitent, I regard it as a high honour to be invited to become Harker's protagonist. The Skye Memoir is a geological masterpiece ; its pages are crowded with an ordered presentation of observational evidence, and discussions of the inferences that may be drawn therefrom. It is, however, from the faithful recording of evidence, left unexplained because his discoveries were half a century ahead of his time, that we can judge Harker's greatness as a geologist. His observations cannot be discredited by references to such mistakes as his misinterpretation of the colonnades of lava flows as sills any more than Hutton's " Theory of the Earth " can be disparaged by references to his misinterpretation of the origin of flints.

After quoting at length my citation of Harker's evidence that the amygdaloidal gabbro in question (in the present connection it is a matter of minor importance what the rock be called) is derivative from amygdaloidal basaltic lava, the amygdales forming relics, Bailey writes with reference to Harker's and my own inferences : " Harker's

statement of evidence is so explicit that it might well be accepted without question, if only it led to some commonplace conclusion ; but such is not the case . . . Accordingly it seems advisable to reconsider carefully the foundations upon which such daring hypotheses, involving either remelt or an unusual type of metamorphism, have been erected." The first part of this statement of Bailey's is quite astonishing ; it is as a result of accepting evidence which does not lead to commonplace conclusions that discoveries are made. When, for example, Becquerel observed that a uranium salt, wrapped in black paper in the dark, imprinted itself on a photographic plate this did not lead to a commonplace conclusion, but to the discovery of radioactivity. Again, when Madame Curie observed that the radioactivity of pitchblende was greater than that of the uranium it contained, this did not lead to a commonplace conclusion, but to the discovery of radium. The second part of Bailey's statement, however, is highly commendable, but unfortunately in his attempt to " reconsider carefully the foundations upon which such daring hypotheses . . . have been erected " he completely ignores the field evidence, i.e. he ignores the very observations upon which the hypotheses were founded. He ignores the observation that amygdaloidal gabbro has been found " only in connection with patches of lava actually enveloped in the gabbro mass or caught between sheet-like prolongations of it " (Harker, 1904, p. 96), and he ignores the observation that no sharp line of division can be drawn between the amygdaloidal gabbro and adjacent highly-metamorphosed amygdaloidal basalt lavas. Instead, relying solely on his own examination of four of Harker's thin sections of the amygdaloidal gabbro Bailey concludes : " I have no doubt that they [the rocks concerned] owe their coarseness to original consolidation and not to subsequent change." Twenty or thirty years ago such expressions of opinion were commonly regarded with respect ; at the present day, with modern techniques at our disposal, they are valueless.

Bailey is mistaken in supposing my suggestion that the Skye amygdaloidal gabbro represents amygdaloidal basaltic lava in which the grain-size has been coarsened by recrystallization implies " an unusual type of metamorphism ". It is common knowledge that recent lava-flows are fine-grained whereas older flows, particularly pre-historic examples, not uncommonly have a doleritic or gabbroic grain-size. Professor Holmes tells me that at Nyamulagira the recent flows are glassy, yet some of the flows only fifty years old have a doleritic grain-size, this contrast being particularly marked amongst the lavas that consolidated in the caldera. Sørensen's (1950) recent study of some Hekla lavas is relevant. He records that the recent lavas are aphanitic, whereas the older lavas are commonly coarse-

grained. Correlated with this increase of grain-size in the older Hekla lavas is a change in the optics of the plagioclases. The plagioclases of the aphanitic flows, which have crystallized from a melt, exhibit high-temperature optics. In the coarser-grained rocks, however, plagioclases with both high- and low-temperature optics are present, the low-optic forms occurring (1) as outer zones sometimes restricted to one end of the larger crystals, and (2) as unzoned plagioclases in the matrix of the rocks. From the presence of many vesicles in the relatively coarse-grained specimens, and the fact that the specimens of the older lavas are generally of the coarser-grained type, Sørensen concludes that the coarsening of grain-size, and the growth of low-optic plagioclases resulted from devitrification and recrystallization of initially glassy and fine-grained lava. The aphanitic lavas of Hekla thus contain orthomagmatic plagioclases with high-temperature optics, whilst the devitrified coarser-grained lavas contain both high-optic and low-optic plagioclases. The fact that the plagioclases having low optics (An_{58}–An_{68}) are richer in lime than those showing high optics (An_{50}–An_{58}) strongly suggests that the devitrification process, responsible for the growth of the plagioclases with low-temperature optics, was a consequence of chemical changes involving enrichment of the lavas concerned in Ca and Al, probably at the expense of Na and Si.

Some insight into the cause of increase of grain-size in lavas is supplied by Fenner's (1936) bore-hole investigations in Yellowstone Park. In the cores from bore-holes in geyser basins Fenner found pitchstones or obsidians, of dacitic composition, to be replaced by quartz and orthoclase, and he demonstrated that the transformation involved a substitution of K for Na, and an addition of Si : the K being supplied by waters rising from greater depth. Furthermore, the Na lost in this interchange is correlatable with the great preponderance of Na over K in the hot-spring waters issuing at the surface. The increase of grain-size in the older lavas at volcanic centres is thus no " unusual type of metamorphism ", but a natural consequence of the long-continued through-passage of gases and water escaping to the surface.

In his description of section 8699 from the Skye amygdaloidal gabbro Bailey unwittingly provides evidence of just this type of recrystallization when he writes : " There are also a few smaller chlorite-filled amygdules, and these on occasion interrupt the form of the bigger feldspars." One amygdale—as seen in section—is actually enclosed by one of the bigger plagioclase crystals. What better evidence could be required to show that these larger plagioclase crystals are younger than the amygdales, and that in consequence they must have grown within the solid rock ?

Added to this is the further evidence that the plagioclases of sections 8698, 8699, and 8701, although approximately euhedral in form, are composed of extremely complex and patchy intergrowths of plagioclases with different refractive indices. Furthermore, these composite plagioclase crystals are dissected by systems of veinlets : some filled with material with a lower refractive index than the dissected plagioclases, and some with chlorite. The evidence suggests a long and complex history of reconstitution.

As Harker (1914, p. 308) remarked on a comparable occasion " we are more likely to reach the truth by trying to understand the conditions than by applying a universal formula of the ' rule of thumb ' order." If Bailey earnestly desires to contribute to our understanding of these rocks by studying thin sections, he should get out his universal stage and measure an appropriate number of Köhler angles on the individuals of the complex plagioclase intergrowths, and thereby discover, as Sørensen has done for the Hekla lavas, whether the plagioclases have high- or low-temperature optics, or whether both types of optics are represented.

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REVIEWS

SELECTED EXERCISES UPON GEOLOGICAL MAPS. By J. I. PLATT. Murby (George Allen and Unwin), London, 1951. 32 pages, with 30 exercises. Price 6*s*.

This is a series of graded exercises overlapping the author's earlier *Elementary Exercises upon Geological Maps*, but proceeding to a more advanced level, and it is a companion volume to his explanatory text *Simple Geological Structures*.

Most of these maps have been used in examinations and it would appear that the instructions to all except five of the exercises were printed on separate question papers and are not reproduced here. This is a pity because there is more challenge to a student to solve a specific problem than just to read the map. It is not so serious, however, as by taking ruler and pencil it is easy to reconstruct the stages by which most maps were drawn and also to spot the occasional anomaly.

Platt claims that the standard of exercise ranges from school certificate to all grades of degree examinations. This is an exaggeration, for there is only a slight increase in real difficulty. Nearly all the maps have the same basic style and the main difference between earlier and later maps is that the latter have more combinations of the earlier themes. These mostly comprise uniformly dipping rocks, unconformities with overstep, faults, and dykes. It is monotonous to find no unconformity with overlap, only translational faults with unit throw, and dykes which replace and never displace the country rock. Here is slender support for studies in structural geology.

There are, however, some interesting problems and this volume adds to the variety from which any teacher may choose and any first and second year student may test himself and for this the author is to be thanked.

W. B. H.

THE FORMATION OF MINERAL DEPOSITS. By A. M. BATEMAN. John Wiley and Sons, New York. 1951. 371 pp., 44*s*.

Dr. Bateman's *Formation of Mineral Deposits* is primarily concerned with general principles and processes, and descriptive detail of individual occurrences and mining fields is omitted. The present volume is essentially a reorganization of Part One of the author's comprehensive technical work, *Economic Mineral Deposits*, and has been specially written for the general reader, mining executive, or student requiring an introduction to the subject. Clear illustration, a readable text, and broad treatment make it well-suited to this expressed purpose.

J. S. W.

VERGLEICHENDE BAUGESCHICHTE DER GEBIRGE. By E. KRAUS. Akademie-Verlag, Berlin, 1951. pp. xvi + 587, 144 text-figs. including 12 folding plates. Price 52 *DM*.

DIE BAUGESCHICHTE DER ALPEN. By E. KRAUS. Akademie-Verlag, Berlin. I Teil, 1951. VOM ARCHAIKUM BIS ZUM ENDE DER KREIDE. pp. xii + 552. 138 figures including 16 folding plates and 9 half-tone photographs. Price 45 *DM*. II Teil, 1952. NEOZOIKUM. pp. viii + 489. 123 figures including 11 folding plates. Price 45 *DM*.

In *Der Alpine Bauplan*, Kraus described the structure of the Alps in terms of a series of transverse sections. This was published in 1936 as volume 1 of a giant concept, *Der Abbau der Gebirge*. Continuity was broken by the war, and the recent volumes develop the same theme under different titles.

Vergleichende Baugeschichte der Gebirge treats the structural history of some of the better known mountain regions. The older systems namely Fennoscandia, the Caledonides, the Variscids, and the Appalachians are discussed first. The Alpine systems are then treated at greater length with

chapters on each of the main ranges surrounding the Mediterranean. A few miscellaneous chapters on other Mesozoic and Tertiary mountains are added, along with a consideration of the principal ocean margins. The last fifty pages develops larger and more general themes.

Treatment of the Alps is omitted from the above, being reserved for more extended consideration in the two parts of *Die Baugeschichte der Alpen*. Throughout these volumes each region is treated in stratigraphical order, and in the Alpine studies there is an ambitious attempt to present successive Mesozoic stages in paleogeographical form with " palinspastic " facies maps. The parts are spread out to imply a crustal shortening in Tertiary time reducing approximately three hundred kilometres to one hundred.

It is well that the Alps have been published in separate volumes for the scale of treatment is entirely different. Outside the Alps a somewhat uncritical compilation results in a series of schematic diagrams and generalizations from which it is difficult to disentangle fact and fiction. Nevertheless, these chapters will prove useful as many conclusions are generally accepted and the references at the end of each form a convenient classified bibliography. In describing the Alps far more detailed information is available, and numerous localized sections are reproduced. The whole is classified regionally within the main stratigraphical divisions. Even if it be an undigested compilation it provides a systematic guide to some three hundred references allowing many of us with only a superficial knowledge of Alpine literature easy access to much new data.

Kraus is one of the most prolific of contemporary geologists and where he is not cataloguing facts his writing is sustained in an inspired style. The motive power behind such industry is a burning faith. This is not concealed. The author's enthusiastic eclectic acceptance of almost any ideas (especially Ampferer's) involving subcrustal flow and convection is revealed not only in every major conclusion, but in his selection of sources, drawing of sections, and almost mystical verbiage. This is frank enough and should mislead no one, while the service rendered in " potting " so much recent literature is a major contribution in the grand teutonic style.

These volumes should be available in libraries.

W. B. H.

PLANE TABLE MAPPING. By J. W. LOW. pp. xi + 365, 148 figs., 8 tables. Harper, New York. 1952. Price 36*s*.

The first three chapters are devoted to elementary principles and practice. The next three explain particular techniques appropriate to three different types of survey : namely small scale, large scale, and reconnaissance mapping. The remaining chapters deal with special topics such as treatment of instruments, vertical and aerial photographs, drawing instruments, and map construction. The whole book is divided into clear brief headed paragraphs, is well indexed, has essential tables, and will slip into any jacket pocket.

This is indeed an excellent manual. It is not merely produced like so many books these days to swell the lists of author and publisher by recasting what is readily available elsewhere. Avoiding the tedium of platitudinous principles and pompous exposition, Low gets straight to fundamentals and from his wide experience goes on to practical details so that both elementary students and practicing surveyors will find what they want rapidly.

The book is designed on the assumption that plane tabling is a fundamental geological survey method. Many geologists in this country will feel that our good large scale topographical maps make this unnecessary. Others, with experience of mountainous terrain, could argue that terrestrial photogrammetry is superior in many respects. In any case it takes several years to become a skilled plane tabler. However, plane table mapping is a fundamental method we should at least appreciate, and this book contains so much

else that is useful to anyone concerned with making maps. It is stiff with wrinkles such as " Ink will not readily collect on the straight edge if a finger is first slightly moistened with oil and then wiped along the bevelled edge . . ."

W. B. H.

THE ELEMENTS OF FIELD GEOLOGY. By G. W. HIMUS and G. S. SWEETING. University Tutorial Press, 1951, pp. viii + 268. Price 14*s*.

There is a good deal in this small book that will be very useful to the Elementary student of geology and help him to make a good start in the subject along sound lines. This applies particularly to Part I of the book wherein the general considerations of field work leading up to the principles involved in mapping are regrettably given precedence over the study of specimens collected in the field (Part II).

Lapworth used to say that there were only two necessities requisite for the young geologist : a good pair of eyes and a good geological hammer. For geology is essentially an out-of-door science and the details of mapping work which may follow the realization of the relation of topography to outcrop will only be successful as a logical consequence of rock formations ; the student should also endeavour to " see solid " (in 3 dimensions) but this will probably come gradually and may be more difficult of attainment.

There is surely far more in elementary field work than just geological map-making though these are certainly an important part of it, but what about the question, for example, of the origin of springs and principles involving wells relating to water supply ? Recognition of differences in mode of occurrence as between Igneous and Sedimentary rocks, and general account of features controlling Mining and all its modern possibilities all are primarily *field* topics.

The matter dealt with in Part II is far too much stressed : it should be only a corollary to field work already carried out. There are also many books already which deal with this part of the subject.

The section dealing with identification of fossils, by what was (mistakenly) believed an original method, actually used in America in 1909, is below the standard of the rest of the book. The subject matter purports to be dealt with from the Palaeozoological and botanical standpoint, but it is unfortunately not always accurate and there is little to suggest the importance of fossils as stratigraphical indices or even a general plan of the evolution of any group. An elementary section on this part of the subject now seems to be badly needed in a modern textbook. It is far more needed than more details for identification of different forms of which many books already have been published.

G. L. E.

CORRESPONDENCE

PLEISTOCENE SECTIONS AT BARRINGTON

SIR,—The recent paper by Mr. B. W. Sparks (*Geol. Mag.*, lxxxix, p. 163) on the Quaternary deposits of Barrington puts on record some extremely interesting points regarding both the stratigraphy and palaeontology of the beds, and all interested in this field will welcome the accession of a young and energetic worker to the difficult problems involved.

The conclusions given in his Barrington paper may perhaps lead people to accept them as beyond question although he has been careful to qualify many of his statements. While not denying that his arguments have much weight I feel it may be as well to point out that his interpretation leaves us with a number of unsolved problems. For instance, it may be easy to explain the absence of Boulder Clay on the slopes of the hills but much more difficult

to explain why no trace of it has been found in the wide valley, if as he claims the valley at its present depth is pre-boulder clay.

The stratigraphical position of the *Hippopotamus* bed at Barrington has always been in doubt and the dating of this important deposit must, I think, wait for stronger evidence than that adduced by Mr. Sparks which rests upon the correlation of the upper part at the *Hippopotamus* site with the lower part of the Cement works site and the argument that the valley was its present depth in pre-boulder clay times.

The age of the plateau boulder clays is still a matter upon which much work remains to be done before finality is reached and I feel it would be dangerous to accept this evidence as being more than a possible indication of the relative age of the drift of the plateau and the fossiliferous deposits of the valley bottoms.

W. B. R. KING.

SEDGWICK MUSEUM,
CAMBRIDGE.
25th July, 1952.

SIR,—In his letter, Professor King has raised two of the main problems of the Pleistocene history of the Cam valley on which the Barrington sections have some bearing, namely the relation between the boulder clay and the topography, and the stratigraphical position of the *Hippopotamus* bed.

In my paper I have stated that the Barrington sections indicate that the main Ashwell branch of the Cam valley predates the boulder clay. Such a conclusion is in accordance with the evidence from some of the other valleys, e.g. those of the Bourn Brook and the Saffron Walden branch of the Cam, where boulder clay can be seen in the bottoms of the valleys, and in accordance with the dissection of the plateau west of Cambridge to 100 feet O.D. beneath the boulder clay. By analogy, and without the additional evidence of the Barrington sections, one would expect the Ashwell branch, the largest valley in the district, to predate the boulder clay. Yet there is the puzzling absence of boulder clay from the valley. If the valley is post-boulder clay, it is difficult to see why such an enormous valley has been eroded here, while little erosion was taking place elsewhere. If it is pre-boulder clay, one must assume that subglacial streams or melt-water streams in the retreat stage resorted the boulder clay into sands and gravels as soon as it was deposited. Such a suggestion seems to me at least as plausible as the supposition that a continental ice-sheet must have deposited a continuous sheet of boulder clay within 40 miles of its margin.

The other problem is that of the position of the *Hippopotamus* bed. The main point in my argument is not the correlation of the lower bed at the Cement Works with the upper bed at Cardo's pit. Both these deposits contain *Helicella geyeri*, a rare snail not found elsewhere in the Cam valley. In addition, *Succinea oblonga*, previously recorded from Cardo's pit, is indistinguishable from *Succinea arenaria* from the Cement Works, while the other *Succinea oblonga* recorded from the Cam valley appear, as far as one can tell from these degenerate shells, to be true *oblonga*. The presence of these two rare shells in both deposits makes their correlation fairly certain, especially as the lithology is the same as well. The crux of the argument is the lithology of the chalk solifluxion: if, by some freak, it could have occurred with boulder clay capping the ridge, my argument fails. But I do not think this likely, as elsewhere in the Cam valley one can see solifluxions derived from high ground capped by boulder clay and their lithology is entirely different from that of the lower bed of Eastwoood's Cement Works.

The position of the *Hippopotamus* bed also seems unique by virtue of its fauna. There are to my mind significant differences between the snail fauna of the *Hippopotamus* bed and that of the Histon Road beds, which have shells practically identical with those found at Barnwell Abbey, Trumpington, and Granchester, and which postdate the boulder clay and belong to the last interglacial period.

Finally, I would like to stress, as Professor King does in his last paragraph, that the description of the Barrington sections was intended to give a relative dating of local deposits, as links between the plateau boulder clay and the valley gravels are uncommon.

B. W. SPARKS.

DEPARTMENT OF GEOGRAPHY,
CAMBRIDGE.
16th August, 1952.

MALVERN TECTONICS

SIR,—I have read Dr. Blyth's recent contribution to Malvern tectonics (*Geol. Mag.*, lxxxix, 1952, p. 185) with great interest. From my own experience of mapping in the south Malverns, one or two points arise, which may be worth adding to Dr. Blyth's account.

I am in agreement with Dr. Blyth's interpretation of the Malverns as a segment of the PreCambrian basement brought up along lines of fracturing; also with his conclusion that the Malvern mass has been forced westward over the adjacent Palaeozoic rocks, rather than the latter driven beneath the PreCambrian by eastward reflected Hercynian movements. In either case, however, the most remarkable feature in this area is surely the moderate nature of the folding in Palaeozoic sediments immediately west of the thrust mass. Here Silurian beds show an open and fairly summetrical folding, modified by slight overturning against the Hereford Beacon. Not only the narrowness of the affected belt of sediments, but the degree of disturbance also, supports Dr. Blyth's contention that the Malvern block is better related to localized movement in the basement, than to crustal shortening on a regional scale. Traced westward this open folding of the Palaeozoic strata passes into a north–south belt of more intense folding and faulting, lying just east of Ledbury. This was demonstrated in the Ledbury tunnel section, and is clearly expressed at the surface from Hope End to Clenchers Mill Wood, south of Eastnor—a distance of four miles. Thus there is the anomaly of gentle folding immediately adjacent to the Malvern thrust mass, with a parallel zone of more intense deformation further away. The latter may perhaps be the superficial expression of a second and equally localized disturbance in the concealed PreCambrian basement.

A second more obvious point is briefly mentioned by Dr. Blyth, but would seem to warrant greater stress. The principal and latest group of movements contributing to the present Malvern range is probably of Carboniferous age; but the Malverns have been a line of recurrent disturbance through very long periods of geological time. The nature and physical conditions of the PreCambrian rocks exposed in the Gullet and Hollybush quarries for example, confirm their lengthy and complex history. The occurrence of fragments apparently derived from these same rocks in the basal conglomerates of both Cambrian and Llandovery beds hereabouts, the presence of included slices of Silurian strata caught up within the thrust PreCambrian, and the occurrence of Warren House pillow lavas at Clutters cave, suggest a repeated elevation and submergence long before Carboniferous times. The present structural pattern of the Malverns represents the cumulative effects of a series of long-sustained disturbances, each early phase contributing in varying degree, but now largely masked by the overriding effects of Hercynian movement.

T. WHITWORTH.

DEPARTMENT OF GEOLOGY,
OXFORD.
12th June, 1952.

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